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GEOLOGICAL SURVEY OF OHIO

EDWARD ORTON, Jr., State Geologist.

FOURTH SERIES, BULLETIN NO. 2.

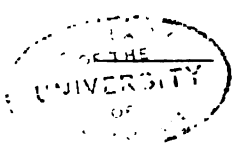
THE USES OF HYDRAULIC CEMENT

BY

FRANK HARVEY ENO, C. E,

Associate Professor of Civil Engineering, Ohio State University.

Published by authority of the Legislature of Ohio, under the supervision of the State Geologist.



COLUMBUS, OHIO, SEPTEMBER, 1904.

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LETTER OF TRANSMITTAL.

To His Excellency, MYRON T. HERRICK, *Governor of Ohio:*

SIR:—I have the honor to present to you, herewith, the Second Bulletin of the Geological Survey of Ohio, which has been prepared under my supervision. The subject of the report is the Use of Hydraulic Cements, and its preparation has been under the special charge of Professor Frank H. Eno, of the Ohio State University, whose thoroughness and devotion to his work I take pleasure in specially commending.

I have the honor to be,

Yours very respectfully,

EDWARD ORTON, JR., E. M.

State Geologist.

Ohio State University:
September, 1904.

OFFICERS OF THE SURVEY.

EDWARD ORTON, JR., E. M. ..... State Geologist
Economic Work in Cement and Clay Industries.

CHARLES SMITH PROSSER, M. Sc. ..... Assistant Geologist
Areal and Stratigraphical Geology.

JOHN ADAMS BOWNOCKER, D. Sc. ..... Assistant Geologist
Economic Work in Oil, Gas, Salt and Coal.

NATHANIEL WRIGHT LORD, E. M. ..... Consulting Chemist
Economic Work on Constitution and Utilization of Coals.

ALBERT VICTOR BLEININGER, B. Sc. ..... Special Assistant
Technological Work in Cement Manufacture.

SAMUEL VERNON PEPPEL, B. Sc. ..... Special Assistant
Technological Work in Lime and Sand Brick Industries.

FRANK HARVEY ENO, C. E. ..... Special Assistant
Utilization of Portland Cement.

METTA L. SEYMOUR ..... Stenographer and Clerk

ANNOUNCEMENTS BY THE STATE GEOLOGIST.

BULLETIN 2.

The following Bulletin deals with the Uses of Hydraulic Cements, a subject on which much accurate information is in existence, though not well distributed among those who have most need of it.

The cement industry, as is well shown in the following pages, is one of the most wonderful examples of the splendid virility of the American nation. In twenty years we have taken it up, perfected it, improved its manufacture, found new uses for it, and after supplying our own fabulously increasing needs, are beginning to look covetously upon the markets of the world, long occupied by the English and Germans. This story reads like a romance, and we little appreciate even now how wonderful an expansion yet lies ahead of us in the use of this supremely convenient and serviceable material.

The Geological Survey of Ohio has examined the cement industry before; a very valuable article on that subject appeared in Vol. VI, published in 1888, from the pen of Prof. N. W. Lord. But since that time the conditions have altered so fundamentally, that it was thought best to take the subject up and thoroughly discuss its present status. Accordingly, three bulletins have been outlined, one upon the Resources of Ohio in the Raw Material for Cement Manufacture; another upon the Manufacture of Portland Cement, and the last upon the Uses of Hydraulic Cements. These three bulletins collectively discuss this subject in a complete manner and it is hoped will be of service in pointing out to the people of Ohio the industrial opportunity which this new material places before them.

The present bulletin is by Prof. Frank Harvey Eno, Associate Professor of Civil Engineering in the Ohio State University. Professor Eno has had much experience in the use of cements; he has laboriously searched the literature of the subject; he has traveled widely to visit and study the typical and important examples of all the uses to which cement is being put. He has, in accordance with my instructions, made this work a popular one—avoiding the symbols of the chemist or the mathematics of the engineer. He has written to reach the people—the great body on whose increasing intelligence in the use of cements depends the still greater expansion of the industry of the future.

While this bulletin is not the record of new and exhaustive researches in this field, at least to any important degree, and was not intended

even to contain a detailed discussion of the many mooted points in the theory of cements, it must not be supposed that it is either loose in its statements, or so general as to be of no value. It has been the aim to present the facts, with such few theoretical considerations as are now generally accepted, in such a simple and clear manner that it will be understood by all. And this has been done in the belief that in all the vast literature of the subject no other work yet accomplishes this simple purpose. How well it may be accomplished here, is a matter on which we will await the public verdict.

FORMER PUBLICATIONS OF THE SURVEY.

The work performed by the First, Second and Third organizations of the Geological Survey of Ohio is comprehended in the following list of publications:

FIRST GEOLOGICAL SURVEY 1837-1838

Title of Volume.	Date of Issue.	Number of Pages.	Number of Copies Printed.	Geologist in Charge.
First Annual Report.....	1838	134	5,000	W. W. Mather
Second Annual Report.....	1838	236	5,000	W. W. Mather

SECOND GEOLOGICAL SURVEY 1869-1888

Title of Volume.	Date of Issue.	Number of Pages.	Number of Copies Printed.	Geologist in Charge.
Report of Progress.....	1869	176	14,500	J. S. Newberry
Report of Progress.....	1870	568	14,500	J. S. Newberry
Report of Progress.....	1871	3	400	J. S. Newberry
Geology of Ohio, vol. I, part I, Geology.....	1872	680	20,000	J. S. Newberry
Geology of Ohio, vol. I, part II, Paleontology.....	1873	*401 †49	20,000	J. S. Newberry
Geology of Ohio, vol. II, part I, Geology.....	1874	701	20,000	J. S. Newberry
Geology of Ohio, vol. II, part II, Paleontology.....	1875	*431 †59	20,000	J. S. Newberry
Geology of Ohio, vol. III, Geology.....	1878	958	20,000	J. S. Newberry
Geological Atlas of Ohio.....	1879		5,000	J. S. Newberry
Geology of Ohio, vol. IV, Zoology and Botany.....	1882	1,070	20,000	J. S. Newberry
Geology of Ohio, vol. V, Economic Geology.....	1884	1,124	10,000	Edward Orton
Preliminary Report on Petroleum and Inflammable Gas.	1886	76	2,500	Edward Orton
Geology of Ohio, vol. VI, Economic Geology.....	1888	831	15,000	Edward Orton

*Pages. †Plates.

THIRD GEOLOGICAL SURVEY 1889-1894

Title of Volume.	Date of Issue.	Number of Pages.	Number of Copies Printed.	Geologist in Charge.
First Annual Report.....	1890	323	10,000	Edward Orton
Geology of Ohio, vol. VII, part I, Economic Geology..	1893	290	2,500	Edward Orton
Geology of Ohio, vol. VII, (complete including part I)..	1894	970	7,500	Edward Orton

FOURTH GEOLOGICAL SURVEY 1899——.

Title of Volume.	Date of Issue.	Number of Pages.	Number of Copies Printed.	Geologist in Charge.
Bulletin 1**.....	1903	320	8,000	Edward Orton, Jr.

DISTRIBUTION OF REPORTS.

First Geological Survey.—These volumes are out of print and rare. They can only be procured from dealers in second-hand libraries and are difficult to obtain even there.

Second Geological Survey.—These volumes were all distributed at the time of their issue. The State retained no stock for meeting future demands, so that no copies of any of these volumes can be obtained from the office of the State Geologist. They can be bought in many second-hand book stores and from dealers in old libraries, at prices varying from a few cents to two or three dollars per volume, according to rarity and demand. Volumes V and VI are the rarest and most sought for.

Third Geological Survey.—These volumes were all distributed at the time of issue, except Volume VII, of which 1,500 were put in the hands of the Secretary of State, for sale at cost of publication. Of these, a few remain at the date of the publication of this volume. The price is $1.50. To obtain copies, send postal or money order to the Secretary of State, State House, Columbus, O. No other volume can be obtained from this source.

The other volumes of this series can be procured only from second-hand book and library dealers.

Fourth Geological Survey.—Under the law, copies of these Bulletins can be bought at the office of the State Geologist, at the cost of

**Price $0.65.

publication. Postal orders, money orders, checks, drafts, or currency must accompany orders. Stamps will not be received.

Bulletin 1—Oil and Gas.....$0.65
Bulletin 2—Use of Cement.....
Bulletin 3—Manufacture of Cement.....In preparation
Bulletin 4—Lime Industry of Ohio.....In preparation
Bulletin 5—Lime-Sand Brick Industry.....In preparation
Bulletin 6—Salt Industry of Ohio.....In preparation

THE LAWS UNDER WHICH THE SURVEY OPERATES.

For the information of the Public, the law under which the work of the Survey is prosecuted is herewith published:—

Laws of Ohio, 1889, Vol. 86, p. 262.

(Senate Bill 409.)

AN ACT

To provide for the extension of the Geological Survey of the State.

Section 1. Be it enacted by the General Assembly of the State of Ohio, That the governor is hereby authorized to appoint a state geologist, whose duty it shall be to continue and extend the investigations already made into the geological structure and resources of the state. Said state geologist shall be appointed for a term of three years, but he may be removed for cause at any time, and a successor appointed in his stead; and the governor is authorized to fill any vacancy which may occur from any cause, at any time. The compensation of said state geologist shall be at the rate of two hundred dollars per month, for the time actually employed; and said geologist shall have power to employ such assistants as he may need; but in no event shall the salary of the geologist, pay to assistants, and expense of the department, exceed the amount of the expenditure authorized by the general assembly.

Section 2. It shall be the duty of said geologist to study, and determine as nearly as possible, the number and extent of the various formations of the state; to represent the same, from time to time, upon properly constructed maps and diagrams; to study the modes of occurrence and the distribution of the useful minerals and products of these formations; to determine the chemical composition and structure of the same; to investigate the soils and water supply of the state; and to give attention to the discoveries of coal, building stone, natural cement, petroleum, gas and other natural substances of use and value to the state. He may also collect and describe the fossils of the various geological formations of the state; but no expenditure shall be incurred under this head that is not expressly ordered and provided for by the general assembly.

Section 3. The said geologist shall make, on or before the first day in February of each year, a report to the governor, covering the work of the preceding year, and the report shall be transmitted to the general assembly, to be printed in the same manner as other public documents, or as shall be otherwise ordered.

Section 4. The salaries of the state geologist, and the assistants employed by him, together with the traveling and incidental expenses, shall be paid monthly, on presentation of properly itemized vouchers, signed by the governor, out of the state treasury, from the appropriation made for such purpose.

Section 5. There is hereby appropriated from the general revenue fund the sum of one thousand dollars annually, for the purpose above named.

Section 6. This act shall take effect and be in force from and after its passage.

NOAH H. ALBAUGH,
Speaker pro tem. of the House of Representatives
THEODORE F. DAVIS,
Passed April 12, 1889. President pro tem. of the Senate.

From the terms of the law, it was evidently intended to provide for the creation of a bureau of geology to which only a portion of the time of the State Geologist should be applied, as the annual appropriation made was much too small to provide the salary of a State Geologist continuously, without making any provisions for office expenses, assistance, etc. It was thought at that time that a few months' work per year would be sufficient to maintain the Survey abreast of geological developments.

The powers and duties of the State Geologist under this act were made so broad and general as to permit carrying on almost any work, so that no new legal provision was thought necessary in connection with re-opening the work of the survey under the Fourth organization. The sum designated in Section 5 is not made a limiting condition of the law, so that the Legislature may appropriate any other amount, at its discretion, for carrying on the work.

Acting under this law, the Legislature has made the following appropriations for geological work:

Designation of Legislature.	Year.	Amount Appropriated.
Seventy-Fourth.....	1900	$2,500 00
Seventy-Fourth.....	1901	$3,500 00
Seventy-Fifth.....	1902	$5,000 00
Seventy-Fifth.....	1903	$3,000 00
Seventy-Sixth.....	1904	$2,800 00
Seventy-Sixth	1905	$2,900 00

The law providing for the publication and distribution of reports is as follows:

Laws of Ohio, 1902, vol. 95, p. 593.

(House Bill, 800).

AN ACT

To Provide for the Publication and Distribution of the Reports of the State Geologist.

Section 1. Be it enacted by the general assembly of the state of Ohio, that whenever the state geologist shall have completed a bulletin upon any of the subjects upon which he is authorized to conduct investigation, he shall notify the state printing commission of this fact, and it shall be the duty of this commission to determine the number of copies which shall be printed, and the grade of paper, the kind of binding, and any other details incident to its proper publication.

Section 2. It shall be the duty of said commission to provide for the publication of said bulletin as soon as possible after the completion of the same. The issue shall consist of a minimum number of three thousand copies.

Of these, one thousand copies, after deducting 200 for the State Library, shall be distributed pro rata among the general assembly.

One thousand shall be distributed free by the state geologist in exchange with other surveys, and with individuals whose services have been used in the collection or preparation of the matter for the bulletins. Of this number not more than four hundred may be distributed during the first year after publication, and not more than fifty in any subsequent year.

One thousand copies shall be set aside for binding along with other bulletins from time to time, when a sufficient number of such bulletins have accumulated to make collectively a volume of from 800 to 1,000 pages. They shall be bound, lettered and numbered, to take their place in the series of volumes already published by the survey.

The distribution of the bound volume of the survey shall be in the hands of the state geologist; but the state library shall receive ten copies, each member of the general assembly one copy, with privilege to draw not to exceed two other copies on application, and public libraries in the state shall be supplied with one copy each. The volumes remaining after these demands have been met may be distributed among the geological surveys and geological societies of the United States and of foreign countries, in exchange for their publications.

Section 3. The board may, at its discretion, order the publication of extra copies in addition to the three thousand already provided for. These extra copies shall be placed in the hands of the state geologist. From these, members of the general assembly may, on application, draw up to fifty (50) copies each. Those remaining shall be placed on sale at a price equal to the net cost of printing and binding, which price is to be established by the state supervisor of public printing. The proceeds of such sales shall be accounted for and paid into the state treasury, and the state geologist shall be required by the commission to give suitable bond for the security of the funds thus passing through his hands. The proceeds of such sales shall be credited to the account of the geological survey and shall be used for the prosecution of the further work of the survey without distinction from other funds which the general assembly from time to time appropriates for the survey.

Section 4. The cost of printing, illustrating, electrotyping, binding, et cetera, of said bulletins and said volumes, shall be paid from the general appropriation for state printing.

Section 5. This act shall take effect from and after its passage.

W, S. McKINNON,
Speaker of the House of Representatives.
F. B. ARCHER,
Passed May 12, 1902. President of the Senate.

THE LIBRARY OF THE SURVEY.

A well equipped geological library is becoming a constantly increasing necessity to the work of the Survey. The library owned by the Survey is now small, as the work of collecting books by exchange or otherwise has been going on only since 1900. The chief obstacle heretofore has been the lack of a definite method of caring for books when obtained. The facts being placed before the Seventy-sixth General Assembly, the following was passed:

Seventy-Sixth General Assembly.
(Regular Session).

SENATE JOINT RESOLUTION No. 22

Relating to the Creation of a Depository for the Library of the Geological Survey of Ohio.

Be it resolved by the general assembly of the state of Ohio, that the state geologist is hereby authorized to enter into an agreement with the board of trustees of the Ohio State University by which the library of the Ohio State University is made the depository for the reports, books, pamphlets, maps, and manuscripts, acquired by exchange or otherwise, which constitute the library of the geological survey of Ohio; said agreement shall provide for the marking, accessioning, cataloging, shelving and ordinary care of said library; the terms upon which said library of the survey shall be available to the use of the students and faculty of the university; the terms upon which the library of the university shall be available for the use of the staff of the survey; and such other matters as the mutual interest and advantage of the two organizations may suggest; provided, that the state geologist shall have no power to permanently transfer the right and title to said library of the survey to the Ohio State University and also that any agreement made shall be without monetary consideration on either side.

GEORGE T. THOMAS,
Speaker of the House of Representatives.
WARREN G. HARDING,
President of the Senate.

Under the authority of the above resolution, the following agreement has been entered into between the Board of Trustees of the Ohio State University and the Ohio Geological Survey:

Agreement between the Board of Trustees of the Ohio State University and Edward Orton, Jr., State Geologist of Ohio.

WHEREAS, During the session of the 76th General Assembly the following joint resolution was regularly passed, viz:

(Resolution quoted above.)

Therefore, we, the Board of Trustees of the Ohio State University, party of the first part, and Edward Orton, Jr., State Geologist, acting for the Geological Survey of Ohio, under the authority of the resolution above quoted, party of the second part, do hereby mutually agree as follows:

I.—That the party of the second part shall deposit in the custody of the Librarian of the party of the first part, all the books, pamphlets, maps, notes and manuscripts now comprising the library of the Geological Survey of Ohio.

II.—That from time to time, where other books, maps, and pamphlets are secured by the Geological Survey of Ohio for its library, whether obtained by gift, exchange or purchase, they shall also be added to those already in the hands of the Librarian of the party of the first part.

III.—That the party of the second part reserves the right to any member of its corps to withdraw any part of the library thus deposited, for use in office or field, but where this is done the usual library receipt shall be taken for matter thus issued. Further, that nothing in this document shall be construed to mean or include the reports, bulletins, or other publications issued by the party of the second part, and which may be held for distribution, exchange or storage.

IV.—That the party of the second part agrees to spend annually such sums for the binding and repair of the books of the said Geological Library as may be necessary, or such part of the sum as the revenues of the Survey permit, but in event that he is unable to incur any such expenditures, then it shall be understood that the work shall remain undone.

V.—That the party of the second part agrees to permit the free use of its Geological library to the faculty, students and visitors of the Ohio State University on the same terms and subject to only the same restrictions as apply to the use of the Library of the Ohio State University.

VI.—That the party of the first part agrees to receive, house, shelve, list, catalog, mark, and otherwise care for the library of the party of the second part, and to put it with the least possible delay in condition for effective use, and to so maintain it during the time this agreement is in force, without any charge for the services thus performed but nothing in this section shall be interpreted to mean the expenditure of money for the binding and repair of the books and documents which are the property of the said party of the second part.

VII.—That the party of the first part agrees to permit the free use of its library to the corps of the party of the second part on the same terms and subject only to the same restrictions as apply to the use of this library by others.

VIII.—That the party of the first part agrees to keep the library of the party of the second part separate and independent from its own library, as to cases or shelves, as to catalogs or card indices, and as to marks or labels in the books, to the end that a separation of the two might easily be made in future without prejudice to the integrity of either, if this contract were nullified by a further act of the Legislature. Provided always, that the card catalog, shelf list and other necessary lists of the library of the party of the second part which may be prepared by the party of the first part shall become a part of said library and go with it in event of separation, and provided always, that nothing in the above section shall be construed to mean that the two libraries or portions thereof may not be kept in the same room or rooms for the greater convenience of their joint use.

IX.—It is the understanding and agreement between these contracting parties, that the arrangement thus entered into under the special authority of this act of the General Assembly of the State of Ohio, is not in the nature of an agreement which may

be set aside hereafter by mutual consent, but that it will require to dissolve the same, an act of the General Assembly similar to that which made it possible at this time.

PAUL JONES,
President of the Board of Trustees.
ALEXIS COPE,
Secretary of the Board of Trustees.
EDWARD ORTON, JR.,
State Geologist of Ohio.

Under the terms of the preceding contract, the books of the Survey have been turned over to the Library of the University and are being catalogued and put into shape for use.

Under the certainty that future accessions can be properly cared for, and conveniently used, the work of forming a regular exchange list with other Geological Surveys and Scientific Societies has been taken up. Up to August 1st, 1904, ninety-four (94) agreements to make regular exchanges of reports and publications have been made, of which sixty-seven (67) are from the United States and twenty-seven (27) are foreign. If this policy of careful and business-like exchange is maintained and the lists increased as opportunity offers, the library of the Survey is certain to become an important one and of great service to its officers.

THE SURVEY IN ITS RELATIONS TO THE PUBLIC.

The usefulness of the Survey is not limited to the preparation of formal reports on important topics. There is a constant and insistent desire on the part of the people to use it as a technical bureau for free advice in all matters affecting the geology or mineral industries of the state. A very considerable correspondence comes in, increasing rather than decreasing in amount, and asking specific and particular questions on points in local geology.

The volume of this correspondence has made it necessary to adopt a uniform method of dealing with these requests. Not all of them can be granted, but some can and should be answered. There is a certain element of justice in the people demanding such information, from the fact that the geological reports issued in former years were not so distributed as to make them accessible to the average man or community today. The cases commonly covered by correspondence may be classified as follows:

1st. Requests for information covered by previous publications.—This is furnished where the time required for copying the answer is not too large. Where the portion desired cannot be copied, the enquirer is told in what volume and page it occurs and advised how to proceed to get access to a copy of the report.

2nd. Requests for identification of minerals and fossils.—This is done, where possible. As a rule, the minerals and fossils are simple and familiar forms, which can be answered at once. In occasional cases, a

critical knowledge is required and time for investigation is necessary. Each assistant is expected to co-operate with the State Geologist in answering inquiries concerning his field.

3rd. Requests from private individuals for analyses of minerals and ores, and tests to establish their commercial value.—Such requests are frequent. They cannot be granted, however, except in rare instances. Such work should be sent to a commercial chemical laboratory. The position has been taken that the Geological Survey is in no sense a chemical laboratory and testing station, to which the people may turn for free analytical work. Whatever work of this sort is done, is done on the initiative of the Survey and not at the solicitation of an interested party.

The greatest misapprehension in the public mind regarding the Survey is on this point. Requests for State aid in determining the value of private mineral resources, ranging from an assay worth a dollar, up to drilling a test well costing several thousand dollars, represent extreme cases. At present there is no warrant for the Survey making private tests, even where the applicant is entirely willing to pay for the service. In many cases individuals would prefer the report of a State chemist or State geologist to that of any private expert, at equal cost, because of the prestige which such a report would carry. But it is a matter of doubt whether it will ever be the function of the Survey to enter into commercial work of this character; it certainly will not be unless explicit legal provisions for it are made.

4th.—Requests from a number of persons representing a diversity of interests, who jointly ask the Survey to examine into and publicly report upon some matter of local public concern.—Such cases are not common. It is not always easy to determine whether such propositions are really actuated by public interest or not. Each case must be judged on its merits. The Survey will often be prevented from taking up such investigations by the lack of available funds, while otherwise the work would be attempted.

The reputed discovery of gold is one of the most prolific sources of such calls for State examination. It usually seems wise and proper to spend a small sum in preventing an unfounded rumor from gaining acceptance in the public mind, before it leads to large losses, and unnecessary excitement. The duty of dispelling illusions of this sort cannot be considered an agreeable part of the work of the Survey, but it is nevertheless of very direct benefit to the people of the State.

BULLETIN No. 2

THE

USES OF HYDRAULIC CEMENTS,

BY

FRANK HARVEY ENO, C. E.

PROFESSOR EDWARD ORTON, JR., *State Geologist:*

DEAR SIR:—In accordance with your letter of instructions issued in June, 1902, I transmit herewith a report upon The Uses of Cement.

I spent a part of the summer of 1902 in traveling through the central and eastern United States meeting cement engineers, makers and users, and observing methods and results of cement construction. The rapidity with which a line of improvement can expand and improve upon its original methods has been an education and a revelation to me. It would be difficult, at the present rate of growth, to keep pace in print with the numerous methods of using reinforced concrete, much more so to present to you a complete list of the various uses of cement. It has been my endeavor rather to present types and to give the essentials necessary to an intelligent use of cement and concrete.

Elsewhere I have expressed my appreciation for the courtesy which many of those connected with cement and concrete construction have extended to me. In this letter, I desire to extend to you my sincere thanks for the help and advice which you have given me.

Respectfully submitted,

June 1, 1904. F. H. ENO.

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INTRODUCTION.

It has been the writer's desire in compiling the following monograph upon the "Uses of Cement" to present as complete a list of uses as it is possible to gather in the limited time available; to present it in as concise a form as a clear description of the use would permit; and to illustrate sufficiently to make clear any curtailed or deficient description. And, further, to bring out by the illustrations details of design, beauty, form and utility, which it would be almost impossible to describe.

It has been the writer's experience, that well chosen pictures, or detailed drawings, may furnish more information of lasting value to one who will examine closely and critically, than pages of written description could possibly afford.

In presenting a subject of this nature, it must, of necessity, be largely a compilation of facts collected from the great number of articles descriptive of the various structures and uses in which cement has been employed. Engineering and popular magazines are full of such descriptive articles upon cement and concrete. It would be next to impossible to give individual credit to each person, firm, or magazine from which the writer has obtained much of the information embodied in this article. He wishes to take this opportunity, however, to express his obligation to them, one and all, and to thank them for information given and kindnesses rendered. He is especially indebted to Mr. Robert W. Lesley, President of the Association of Portland Cement Manufacturers, for copies of his "History of the Portland Cement Industry in the United States," and other articles upon cement, and for a carefully compiled list of the novel or new uses in which cement has been employed within the last two years.

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UNIVERSITY OF

CHAPTER I.

A BRIEF HISTORY OF CEMENT.

Cummings in his "American Cements" says: "The fact is, the history of natural rock cement reaches so far back into the early ages, that it is impossible to learn precisely the date of its earliest fabrication. But we do know that ancient Egyptians made natural cement 4,000 years ago, which set under water. The Romans over 2,000 years ago used it in sewer and water mains, fountains, etc. Prior to this an aqueduct over 70 miles in length was built for the ancient city of Carthage. At one place it was carried across a valley on arches over 100 feet high, 1,000 arches in the line. Immense quantities of natural cement were used in its construction. Some of these arches are still standing. At one point where the arches are the highest, a piece over 100 feet long has fallen from the top of the aqueduct to the rocks below and still lies there intact, unbroken, illustrating the toughness, tenacity and durability of the natural rock cement."

Shadwell in "The Architectural History of the City of Rome" says that the earliest use of lime mortar among the Romans dates back to 175 B. C. to the construction of the "Emporium," the walls of which are a mass of concrete, rough stone and mortar. From this time on much concrete was used in the walls of buildings, fortifications, aqueducts, etc.

The Colosseum, built by Vespasian and Titus, A. D. 75 to 80, was largely of concrete walls with cut Travertine stone, having the inner walls faced with brick.

The aqueducts, in order to make them impervious, were lined with a cement mortar composed of crushed fragments of brick with fresh lime, called by the early Romans, "Opus signinum;" it is still known and used in Rome under the name "cocciopesto."

Another form of concrete known as "Opus Reticulatum," looks like brick work, but is composed of a lime concrete wall having wedge shaped pieces of Tufa driven into the face of the wall before the concrete attained full set. It is said that some 25 or 30 years ago an attempt to destroy such a wall on the Quirinal, failed on account of the immense expense required due to the extreme hardness and toughness of the concrete, such walls being indestructible except by the use of dynamite.

This failure seems to imply one of two things, either that ancient concrete was very superior in toughness to anything we now construct, or else, that the Latin race lacks much of the vigor and persistency which the Yankees possess; for, elsewhere in this paper an account is given of the successful removal of a solid concrete monolith of great toughness in preparing the foundations of the new post office building in Chicago.

The dome of the Pantheon, which was erected at the beginning of the Christian era, is of concrete supported in a frame work of brick arches. It has an internal diameter of 142 feet. For 2,000 years nature has been expending her energies upon the structure, but it still survives to tell the story of the durability of concrete. Figure 1 shows this remarkable building.

Fig. 1.—View of the Pantheon at Rome.

"The Pantheon at Rome is the most perfect existing classical building in that famous old city. It was built by Agrippa, 27 B. C., nearly 2,000 years ago. The circular walls are about 20 feet in thickness, and the roof is a hemispherical cement concrete dome with a thirty-foot opening in the top and spanning in the clear 142 feet 6 inches. This is the most remarkable instance in the world's history showing the great strength, durability and permanence in cement concrete construction. It has baffled the destructive elements of time for nineteen centuries and shows not a single crack to-day."

Cummings says that in Mexico and Peru, natural rock cement was used so long ago in stone masonry that the stone has worn away leaving the projecting mortar joints.

MODERN CEMENTS.

Cements, as we know them today—meaning either natural or Portland cements—were not known commercially until the beginning of the last century. Indeed, Portland cement has not been manufactured on a commercial scale much longer than 50 years. The Roman cement was a natural cement, even more natural than cement bearing that name today—because it needed no burning, but was manufactured directly from the volcanic ashes around Mount Vesuvius, especially those found near Pozzuoli, and it was therefore called Pozzuolana.

Cements in England.—The first cements manufactured in modern times were made in England and were called "Roman Cements" from their resemblance to the old Roman cements which hardened under water. In 1756 while preparing to build the Eddystone light-house, John Smeaton began investigations which led to the discovery that argillaceous limestones produced limes that would set under water, called hydraulic limes. He carried his investigation far enough to secure a good hydraulic lime or natural cement, which through its durability in the Eddystone light-house gave Smeaton lasting fame in engineering science. The Eddystone light-house built in 1756-58 by Smeaton was on a very exposed coast in the English Channel south of Plymouth. It was rebuilt in 1882, not because of the failure of Smeaton's cement, but due to the wearing away of the solid rock beneath the tower.

In 1796, Joseph Parker, manufactured a Roman cement by calcining and crushing septaria nodules found on the Isle of Sheppey just off the coast of Kent, England. Parker's patent, dated June 28, 1796, and numbered 2120, claims the invention of: "A certain Cement of Terras (trass) to be Used in Aquatic and other Buildings, and Stucco Work."

He described his process as follows:

> "The principle and nature of said invention consists in reducing to powder certain stones or argillaceous productions, called noddles of clay, and using that powder with water so as to form a water (mortar?) or cement stronger and harder than any mortar or cement now prepared by artifical means. I do not know of any precise general term for these Noddles (?) of clay; but I mean by them certain stones of clay or concretions of clay, containing veins of calcareous matter, having frequently but not always water in the center, the cavity of which is covered with small crystals of the above calcareous matter —being burned with heat stronger than that used for burning lime—and by having water thrown upon them, and being reduced to powder after burning, and being mixed with water just sufficient to make them into paste, become indurated in water in the space of an hour, or thereabouts. Any argillaceous stone, then, corresponding with this description, whether known by the name noddles of clay, or any other name, is the sort and kind only that I mean to appropriate to my own use in the fermentation (formation?) of my cement."

Natural cement was produced at Boulogne, France, in 1802, from Septaria, called Boulogne pebbles.

Edgar Dobbs, of Southwark, London, took out a patent in 1810 on a manufactured artificial hydraulic lime, or cement, made by mixing carbonate of lime and clay, drying, molding and burning sufficiently to expel the carbonic acid without vitrifying the substances.

Joseph Aspdin, a brick mason of Leeds, England, first manufactured a real artificial cement, which process he patented in 1824 and called the product Portland cement because the artificial stone produced from such cement was very similar in character and appearance to the noted building stone obtained in the quarries on the island of Portland, in Dorsetshire, England.

Portland cement did not become an acceptable building material, however, until John Grant, an eminent engineer, employed on the London drainage works in 1850, had thoroughly tested it and discussed its use in a scientific manner, and had written several clever articles upon the subject for the institute of civil engineers. From that day until the present time it has been an important material in English construction. England led in the manufacture and use of Portland cement for 25 years, but Germany finally took the lead in its production and it is only within the last two years that the United States has passed all other countries and approached Germany in the development of the cement industry.

In 1900, England produced between 7 and 8 million barrels of Portland cement.

Cements in France.—The growth of the cement industry in France has not been so marked as it has been in several other countries, but her chemists have led in first establishing the true principles of hydraulic cements. In 1802 natural cement was produced at Boulogne from Septaria. In 1813 to 1818 M. Vicat produced hydraulic lime or natural cement artificially by mixing chalks and clays. In 1846 the manufacture of Portland cement was first begun in France near Boulogne.

The output of Portland cement in France for 1900 was about 3,500,000 barrels.

Cements in Germany.—In Germany the first Portland cement works were established at Stettin, in 1855, in the now famous Hamburg Portland cement district. The growth of the production of Portland cement in Germany was almost as phenomenal as it has been during late years in the United States. From a production of 30,000 barrels in 1855, the production grew until in 1877, 29 factories produced 2,400,000 barrels. In 1886, 42 factories produced 5,700,000 barrels. In 1900, 70 factories produced nearly 20,000,000 barrels.

For many years Germany has exported two to four million barrels of cement each year to the United States besides its exports to other countries.

In 1901, however, the exports of German cements to the United States fell below 600,000 barrels.

Cements in the United States.—The first discovery and manufacture of cement in the United States was made in 1818 by Canvass White, who took out a patent on Roman cement which he manufactured from the natural rock near Fayetteville, New York. This was used in the masonry work on the Erie canal.

A diary,[1] kept by one of the ancestors of Mr. Samuel T. Wagner, M. Am. Soc. C. E., during a trip over the Erie canal while it was under construction, reads as follows: "An important discovery by Mr. White of a lime whose properties resemble and are equal to the Roman cement aided the construction and greatly insures the permanent duration of the massive and important masonry of this great work. Experience and time have established its power to harden under water. It contains 35 parts carbonic acid, 25 parts lime, 15 parts silex, 16 parts alumine, 2 parts water and 1 part oxide of iron. It is calcined, ground and mixed with an equal weight of sand and but little water. It is found in inexhaustible quantities."

In 1824, natural cement rock was found at Williamsville, Erie county, New York. This discovery was also brought about by the necessities of the Erie canal. A natural rock cement was manufactured at Kensington, Conn., in 1826, while the first works in the famous Rosendale district in New York were not established until 1828.

Quoting from Mr. Robert W. Lesley's paper, "History of the Portland Cement Industry in the United States," he says:

"The first large public works built in this country were the canals, and the most necessary thing to build a canal was mortar that would hold the stones together at the locks, or walls, under water. Consequently, wherever canals were to be built, there was a search for cement rocks, and all the earliest works in this country were established on the lines of canals. Thus, on the Chesapeake and Ohio are the Cumberland and Round Top works; on the Lehigh canal the works at Siegfried and Coplay, Pa.; on the Richmond and Allegheny, the works at Balcony Falls, Va.; on the Delaware and Hudson canal, the large group of works at Rosendale and Kingston, and at the Falls of the Ohio canal, the large aggregation of works at Louisville."

He might have added also, on the Michigan and Illinois canal are the works at Utica, Ill. The works at Louisville were established about 1829, while the works at Utica, Ill., were founded in 1836-38.

The First Portland Cement in the United States.—The first Portland cement manufactured in this country was made from natural rock by Mr. David O. Saylor, of Coplay, Pa. He had been making natural rock cement for several years, when he turned his attention to the production of a more perfect cement in the early seventies. By careful selection, grind-

[1] *Eng. Record*, Oct. 8, 1908.

ing and mixing he produced a Portland cement which he exhibited at the Centennial Exhibition in 1876 at Philadelphia. This cement compared favorably with the imported cements of that date.

Up to 1880 five other works were established as follows: At Rondout, N. Y., Kalamazoo, Mich., Wampum, Pa., South Bend, Ind., and Rockland, Me. Of these six works but three have made sufficient success to survive. In reality the Portland cement industry in the United States as a commercial success dates back no further than 1882; 21 years of Portland cement life brings us to the year of its majority, 1903. Below is given a table showing the production of Portland cement in this country and the importation of foreign cements from 1880 to 1902 inclusive.

TABLE I.

Table Showing Production of American Portland Cement, and Importation of Foreign Portland Cement for years 1880 to 1902, inclusive.

Year.	American.	Foreign.	Year.	American.	Foreign.
	Barrels.	Barrels.		Barrels.	Barrels.
1880	42,000		1891	454,813	2,988,313
1881	60,000		1892	547,440	2,440,654
1882	85,000	370,406	1893	590,652	2,674,149
1883	90,000	456,418	1894	798,757	2,638,107
1884	100,000	585,768	1895	990,324	2,997,395
1885	150,000	554,396	1896	1,543,023	2,989,597
1886	150,000	915,255	1897	2,677,775	2,090,924
1887	250,000	1,514,095	1898	3,692,284	2,013,818
1888	250,000	1,835,504	1899	5,652,266	2,108,388
1889	300,000	1,740,536	1900	8,482,020	2,386,683
1890	335,500	1,940,186	1901	12,711,225	939,330
			1902	17.230,644	1,961,413

CHAPTER II

THE USES OF CEMENT IN MORTARS.

There are three general forms in which cement is used, namely: (1) in mortars, (2) in plain concrete and (3) in reinforced or steel concrete construction.

As a mortar, it may be used either in a neat paste, or as a real mortar of cement mixed with sand. In the mortar form it is used for jointing all classes of masonry, for plastering walls and masonry surfaces, for fillers in street paving, for nearly all classes of ornamental work, for roofing-tile, for special processes of hardening quicksand in order to permit of excavation, for a protective coating to the metal work of bridges and viaducts to prevent rust and corrosion from the smoke blast of locomotives, etc., etc.

THE DEVELOPMENT.

Cement was undoubtedly first used in the form of mortar in laying stone or brick masonry. If a history of the development of masonry were written, the chronological steps of its progress would probably assume the following order: first, rough stones piled loosely in wall or pier form; second, selected stones with flat or squared surfaces set up in more regular forms, as was done by the ancient Hebrews in building their altars; third, selected stones, chipped into still more rectangular shapes and more carefully laid into regular forms of construction; fourth, to insure greater stability, mud paste, clay, or bitumen was used to cement the stones in place, and, finally, a mortar of lime or puzzuolana was discovered and used which insured permanency and durability to the work.

The oldest mortar so far discovered appears to be that found by Mr. Wm. Clarke, a civil engineer of England, who brought back for analysis a piece of mortar secured from the ruins of an ancient Phoenician temple near Larnaca on the island of Cypress. Mr. Wm. Wallace, in a paper read before the Mechanics' Institute, at Glasgow, says (speaking of this mortar which he had chemically analyzed): "Mr. Clarke supposes this to be the most ancient mortar in existence." He says further, "It is exceedingly hard and firm—and appears to have been made of a mixture of burnt lime, sharp sand and gravel." Of another specimen from the great Pyramid of Cheops, Mr. Wallace says, "Two specimens of mortar from the Pyramid of Cheops were examined, one from the interior and the other

from the outside—both present the same appearance, that of a mixture of plaster of a slightly pinkish color with crystallized selenite or gypsum. They do not appear to contain any sand. The mortar is easily reduced to fragments, but possesses a moderate degree of tenacity." While the chemical analyses given by Mr. Wallace of both mortars do not parallel the usual Portland cement analyses, they do show that the ancient people knew how to manufacture the materials for a very durable mortar. Another specimen, Mr. Wallace says, "was taken from the Pnyx, in Athens, the platform from which Demosthenes and Pericles delivered many of their orations. It has been long exposed to the action of the weather, is very hard, and of grayish white color."

While these specimens show the antiquity of mortar and how durable even a poor mortar may be, it is only within the last century and particularly the last decade that the high development of cement manufacture has brought into use mortars that are nearly perfect and almost indestructible.

THE ADVANTAGES OF CEMENT MORTAR OVER LIME MORTAR.

The uniform bearing and equality of support in the bed of each block of stone aids in securing strong and durable masonry. Lime mortar has furnished a masonry construction which has endured for centuries under trying conditions, yet for modern requirements in large warehouses, sky-scraping office buildings and massive chimneys and bridge piers, a mortar which will more nearly equal in strength that of the building material used, is needed. Lime mortar simply furnishes a bed for the stone or brick, a bed which has but a fractional part of the crushing strength which stone or well made brick possess. With good cement mortar, however, a bed or joint is provided which continues to harden until frequently it will sustain greater strains without rupture than the body of the masonry itself can withstand.

With lime mortar there are several weak characteristics, namely, lack of tensile or cohesive strength, lack of crushing strength, porosity, inability to harden under water, and the necessity for contact with air, that the mortar may receive sufficient carbonic acid to thoroughly set.

Baker in his "Masonry Construction" gives the tensile strength of lime mortar of the proportions of 1 lime paste to 3 sand at one year old, as 50 pounds per square inch. The present American Portland cements in mortars of the same proportions and age will run from 350 to 450 pounds per square inch.

The crushing strength of mortars are about 8 to 10 times their tensile strength and the same relative difference still exists between lime and Portland cement mortars, making the compression strength of Portland cement mortar from 3,500 to 4,500 pounds per square inch.

The average tensile strength of 12 American Portland cements in mortars of 1 cement and 3 sand, one month old, tested at one laboratory,

was 308 pounds per square inch. The average of six cements, at another laboratory, tested at six months of age, was 404 pounds. The average of 14 American and German cements at one year old, in proportions of 1 cement and 3 sand, was 361 pounds. The average of tests from ten different cement testers upon Giant Portland cement mortar, 1 cement and 3 sand, one year old, was 414 pounds; while 8 of the same testers gave results for 1 cement and 2 sand which averaged at one year old 492 pounds.

Actual crushing tests upon 12 inch cubes of Giant cement concrete, 3 months old, made in the proportions of 1 cement, 3 sand, and 5 broken stone, and tested at the government testing laboratory, gave crushing strengths varying from 3,081 pounds to 4,451 pounds per square inch and averaging over 4,000 pounds per square inch. Such concrete would support a column of its own material 3,600 feet high without crushing.

Where thick or heavy masonry work is to be built, the interior mortar joints are more or less excluded from contact with air, and consequently from the carbonic acid contained in the air, hence it is safe to conclude that it will take long periods of time for the lime mortar to become perfectly hardened. During this time the structure is liable to settlement and deformation, therefore the necessity of some more permanent and quickly hardening material for mortar.

Baker says in a note on lime mortar, "Lime mortar taken from the walls of ancient buildings has been found to be only 50 to 80 per cent. saturated with carbonic acid after nearly 2,000 years of exposure." "Lime mortar 2,000 years old has been found in subterranean vaults, in exactly the condition, except for a thin crust on top, of freshly mixed mortar."

For the heavy structures of the present day it is quite apparent that such defects would be dangerous.

The question of protection from the destructive action of the elements is often as important a factor of consideration with smaller structures as it is with the larger ones. The porosity of lime and mortar would allow moisture and temperature changes to affect the durability of such work. Cement mortar, upon the other hand, can be made impervious to water. It will set under water and without contact with air and will continue to gain strength for an unknown period of time. Cement mortar in the center of a thick wall will be practically as hard and durable as the exterior surface at the same age.

Lime mortar is of no value in submarine work. Good, durable masonry can not be laid in water without cement mortar. The fine breakwaters lately constructed by the United States Government at Buffalo and Cleveland, the concrete jetties at the mouth of the Mississippi river, the sea-walls around Galveston, Texas, and Havana, Cuba, all illustrate the value of cement in marine or hydraulic service.

NATURAL VERSUS PORTLAND CEMENT.

The question of whether to use natural or Portland cement mortar depends upon the strength required, upon the time which can be allowed for the mortar to gain sufficient strength for the immediate requirements of the work and upon the relative price of the two cements.

It may be that a rapid setting mortar is needed without great ultimate strength; if so, a natural cement will fulfill the requirements at a less cost than Portland cements. The time of setting of both natural and Portland cements varies so widely with different brands that only general limits may be stated. Natural cement usually begins to set in from five to forty minutes, and attains its permanent set in from twenty minutes to two and one-half hours, while Portland cement begins to set in from three-fourths of an hour to three hours and attains its final set in from two and one-half to eight hours. Some experimental Portlands, however, have been known to begin setting within three minutes and to have attained hard set in fifteen minutes.

To illustrate the question of relative cost and strength of the two cements, suppose the specifications for a certain structure call for a cement which shall develop an ultimate tensile strength in the work, of 200 pounds per square inch. Most of the natural cements in mortars of 1 cement to 2 sand will develop that strength in three months, and greater strength in six months or a year; while Portland cements will give similar strengths if mixed in the proportion of 1 cement to 4 or 5 sand. Assuming sand at $1.25 per cubic yard, natural cement at 90 cents per barrel of 265 pounds, and Portland cement at $2.50 per barrel of 380 pounds, the material for a cubic yard of mortar will cost:

TABLE 2.

For Portland Cement Proportions 1 to 5.			For Natural Cement Proportions 1 to 2.		
0.92 cu. yds. of sand at	$1.25	$1.15	0.81 cu. yds. sand at	$1.25	$1.01
1.12 bbls. cement at	2.50	2.80	2.49 bbls cement at	.90	2.24
		$3.95			$3.25

From this comparison it is seen that a natural cement mortar of 1 cement, 2 sand, is 70 cents cheaper per cubic yard than a Portland cement mortar of 1 cement to 5 sand, both mixtures having about the same tensile strength. These comparisons, however, can only be made under known conditions, the proportions being dependent upon the weight of the cement and sand per cubic foot, the voids in the sand and the amount of water used in the mixing, while the amount saved is greatly influenced by the relative cost of the two cements and the cost of the sand.

When great ultimate strength is required, or when variable strains occur in a structure, Portland cement should be used.

MIXING THE MORTAR.

In preparing mortar the sand and cement should be thoroughly mixed dry and then water added and the mass carefully mixed again, until the mortar has a proper and uniform consistency to work easily and smoothly under the trowel. The strongest mortar for any given sand and cement is produced when sufficient cement is used to just fill all the voids in the sand with a thin coating of cement over each grain of sand. Sands vary greatly in their coefficient of uniformity. Some sands are all fine, some all coarse, while many are graded from very fine to very coarse. It follows, therefore, that a graded sand requires less cement to make a mortar having a given strength, than a sand which has uniform size. The voids in the latter sand amount to nearly 50 per cent. of the mass.

EFFECT OF VARIOUS SANDS UPON THE STRENGTH OF MORTAR.

Standard quartz sand has about 48 per cent. of voids in it when measured dry. Lake sand from Sandusky, Ohio, has about 35 to 37 per cent. of voids. Bank sand from Mock's sand bank northeast of Columbus, containing considerable clay or loam, has about 33 to 34 per cent. of voids.

A class in civil engineering at the Ohio State University carried on extensive tests during the winter term of 1902-03, with several brands of cement and the three kinds of sand named above. The characteristics of the sands were as follows:

TABLE 3.—Characteristics of Sands.

Kind of Sand.	Fineness—per cent. of sand remaining on a			Passing a No. 50 Sieve.	Voids Per Cent.	Weight per cu. ft.	Remarks.
	No. 20 Sieve.	No. 30 Sieve.	No. 50 Sieve.				
Crushed Quartz	0	100.0	0	0	47.5 to 49.0	83	Clean.
Lake Sand.	7.7	16.7	26.5	49.1	35 to 37	103	Clean.
Bank Sand.	11.6	37.0	33.4	18.0	33 to 34	102	Contains about 7% of loam.

Among the cements tested were the Atlas, Giant and Dyckerhoff brands of Portland cement. Seven and twenty-eight day tests were made. The results of the 28 day tests are given in table number 4. While the table shows quite a variation in the results obtained by the different testers, it certainly shows a remarkable uniformity in results when the

inexperience of the class is taken into consideration. One thing is quite markedly shown in this table and is corroborated by a large number of other tests, *i. e.*, the increase in tensile strength shown in the mortars made with the bank sand over those made with the other sands, especially in 1 to 2 or 1 to 3 mortars. One of the important features of the table is its comparative value for illustrating the personal factor in cement testing.

TABLE 4.

Twenty-eight Day Tests of Cement Mortar Briquettes—1903.

Tester.	Neat	Standard Sand.			Lake Sand.			Bank Sand.			Cement
		1-1	1-2	1-3	1-1	1-2	1-3	1-1	1-2	1-3	
C. L. Bushey	799	747	466	235	531	363	216	534	427	291	Atlas
L. Eysenbach	800	767	400	231	585	322	182	602	418	367	"
Edw. Thomas	770	524	359	210	474	221	222	*393	*302	*265	"
C. A. Melick	769	586	450	229	524	297	248	627	509	318	"
E. R. Brashear	778	701	240	246	595	380	204	656	556	390	"
W. J. Barry	813	700	442	206	560	312	203	632	492	342	"
Averages	788	671	360	226	543	316	212	574	451	329	
C. W. Schubert	908	783	505	252	630	458	278	640	550	354	Giant.
J. L. Murphy	970	633	456	245	600	436	226	571	431	318	"
C. L. Hill	1015	702	557	347	627	458	314	556	453	364	"
J. H. Chubb	1231	868	600	381	733	476	366	687	649	472	"
Averages	1031	746	529	306	647	457	296	613	521	377	
J. H. Chubb	681	490	439	300	514	406	316	570	504	418	Dyck
J. L. Murphy	567	510	415	280	352	340	283	430	415	356	"
C. L. Hill	480	460	434	302	426	362	283	520	444	342	"
C. W. Schubert	620	485	345	235	409	283	242	550	483	420	"
W. J. Barry	531	412	312	174	387	337	242	567	442	332	"
C. A. Melick	442	463	374	250	329	264	233	606	510	321	"
E. R. Brashear	618	467	390	235	393	355	282	580	496	266	"
Edw. Thomas	487	360	308	234	312	215	212	390	212	232	"
L. Eysenbach	532	385	378	180	396	317	206	414	433	353	"
C. L. Bushey	640	425	370	189	354	300	249	418	425	345	"
Averages	560	446	377	238	387	318	255	505	436	339	

* Composed of a mixed sand.

There may be several reasons for this increased strength of the bank sand mortar over the clean lake and quartz sands; but it is the writer's opinion that the principal reason is found in the smaller percentage of voids and the consequent surplus amount of cement which can go towards coating every particle in the aggregate. An examination of the table of characteristics of these sands shows that nearly one-half of the lake sand passes through a sieve of 2,500 meshes to the square inch. This accounts at once for the greater percentage of voids which must be thoroughly filled with cement in order to give greater strength to the mortar. This fine portion of the lake sand is composed of small, rounded and very smooth particles of quartz which naturally have no interlocking qualities, and must therefore depend entirely upon the adhesive powers of the ce-

ment upon their hard smooth surfaces to give strength to the mortar. The increased strength of the standard quartz mortar is largely due to the irregular rough grain of the sand which allows the grains to interlock and which also gives rough adhesion surfaces for the mortar contact.

THE EFFECT OF FINE SAND UPON THE STRENGTH OF MORTAR.

During the last winter the writer carried on a few tests to determine the effect of fine sand upon cement mortar. Similar and more extensive tests have been carried on by others, and in the main all agree that fine sand weakens cement mortar. The tests made by the writer are here presented in tabular form:

TABLE 5.

Effect of Fine Sand Upon Cement Mortar.

Lake Sand.	Per cent. of Water.	1 to 1 Mortar. 7 Days.	28 Days.	3 Mos.	Per cent. of Water.	1 to 2 Mortar. 7 Days.	28 Days.
Passing a No. 50 Sieve	11	315	395		14	315	367
	15½	426	578	668			
	18	394	533	617			
Remaining on No. 50 Sieve	12½	517	514	629			
Remaining on No. 30 Sieve	12½	546	625	650			
Remaining on No. 20 Sieve	12½	495	599	613			
Remaining on No. 16 Sieve	12½	460	521	557			
Standard Quartz	12½	535	632	740			
Lake Sand Unsieved	14	500	581		12½	367	428

The number of the sieve designates the number of meshes to the linear inch. The tests show a marked increase in strength in mortars from fine to coarse sand, up to the size of the standard sand grain; from that size up the strength seems to decrease. It may be noted that the lake sand between the 20-30 sieves gives results comparable with the standard quartz mortars. The general results of these tests agree quite well with the results of other testers.

This series of tests was limited, only about 150 briquettes being broken. But the tests were made with great care in all details and will give a general idea of the action of fine sand upon cement mortar.

The unsieved lake sand occupies a place intermediate between the 50 and the 30 sieve. The results with different proportions of sand would probably differ slightly, but the two sets of briquettes broken from the 1 to 2 mortar indicate relatively similar results.

The following table taken from the "Directory of American Cement Industries," being the result of a series of tests made at the Holyoke Dam, Massachusetts, and supplemented by some of the writer's tests, shows the effect of adding sand to cement in reducing the strength of the mortar. All tests were tensile tests upon mortar briquettes 28 days old, made from high grade American Portland cements.

The results of the Holyoke test are given in column number 3 and the writer's tests in column number 4.

TABLE 6.

Strength of Various Grades of Mortar.

Cement.	Sand.	Tensile Strength. Pounds per square inch.	
1	2	3	4
neat	0	889	873
1	1	805	581
1	2	589	428
1	3	343	275
1	4	204	211
1	5	133	161
1	6	121	
1	7	71	
1	8	53	
1	9	44	

EFFECT OF WATER UPON THE STRENGTH OF MORTAR.

Another feature plainly noticeable in mortars is the effect of the proportion of water used upon the strength of the mortar. Too much or too little water greatly reduces the strength of the mortar. Each sand and each cement influences the amount of water necessary to make the strongest mortars. In general, fine sands and loamy sands require more water than coarser and cleaner sands. Natural cements require more water than Portland cements. Mortars of 1 sand to 1 cement require more water than mortars having greater proportions of sand. Too little water making a stiff mortar, will increase the cost of working with it during construction and will decrease the perfect crystallization, thus decreasing the strength. Too much water acts as a dilutant, leaving the mortar porous when hardened and consequently not so strong as dense mortar. When mortar is placed where it will get very little additional moisture over that used in mixing it, sufficient water should be used to thoroughly hydrate the cement.

The writer in making laboratory tests found that a set of briquettes made from standard sand and Portland cement with 12½ per cent. of water, lost one-sixth of the water in the 24 hours that the briquettes remained in the air, although they were covered with a dampened cloth.

They regained one-half of the lost water after five days under water. If so much water is lost under such conditions, it is readily seen what a serious loss must occur in actual practice unless unusual care is taken to protect the mortar surface. There is no question but that this loss of water seriously impairs the strength of the mortar.

The three sets of tests with fine sand in table number 5 illustrate the effect obtained by using varying percentages of water. The table shows that from 7 to 10 per cent. of tensile strength is lost by using too much water, and from 30 to 40 per cent. by using too little. This illustrates the necessity of properly proportioning the water to the cement and sand used. The water used was proportioned by weight to the combined weight of sand and cement.

PERMEABILITY OF CEMENT MORTAR.

Work of Melick and Shepherd.—In 1899 and 1900,* Messrs. N. A. Melick and C. W. Shepherd, students in the Ohio State University, carried on, under the direction of the late Prof. C. N. Brown, a series of tests to determine the permeability of cement mortar. The question they sought to answer in reference to permeability, propounded by Mr. Julian Griggs, M. Am. Soc. C. E., Chief Engineer of the City of Columbus, Ohio, was this: "Is it necessary to use soap and alum and Silica Portland cement, or can a cheaper mixture be made impermeable."

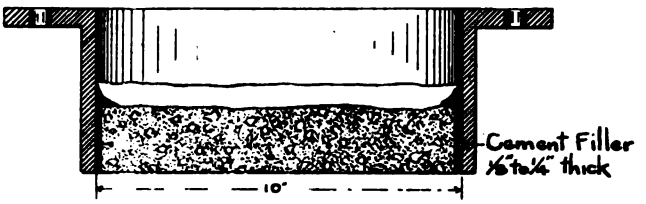
The experiments were carried on with three kinds of sand; standard sand or crushed quartz passing a No. 20 sieve and being held upon a No. 30 sieve, lake sand, and a mixture of equal parts of lake sand and quartz. Medusa, Dyckerhoff and Silica Portland cement were used. The water pressure was applied to the cement mortar by means of a ¾ inch pipe threaded into the back of a metal disc, 15 inches in diameter. Bolted to the face of this disc was a flanged metal collar, 10 inches in diameter. Within the collar was rammed from 2 to 3 inches of the mortar, the permeability of which was to be tested. A neat cement filler ⅛ inch to ¼ inch thick was troweled around the ring to prevent water leaking between the collar and the concrete. Figure 2 shows a section of collar filled with mortar ready to bolt on to the disc. The mortar was mixed so dry that water would just flush to the surface upon thorough ramming. Great care was taken to get uniform ramming over each portion of the disc; the rammer being constructed in the form of a double sector just fitting within the metal collar.

After investigation of actual work being done in Columbus, O., the young men estimated that in ramming, 8 foot-pounds of work were done upon each square inch of surface of the concrete which the city was laying. Hence they designed the rammer so that they could easily do a similar amount of work upon the ramming of the mortar into these collars.

*Taken from the thesis of Messrs. N. A. Melick and C. W. Shepherd, civil engineering graduates from the Ohio State University in 1900. The work was done at the suggestion and expense of the Engineers' Club, of Columbus, Ohio.

The mortar collars were kept in moist air for twenty-four hours and then stored in water for twenty-seven days before being tested. The water pressure in testing varied from 25 to 65 pounds per square inch.

It was found that discs which did not leak in twenty-four hours would never leak. To be considered permeable, it was decided that drops of water must collect upon the outer surface of the mortar disc. Where discs became damp, but sufficient moisture did not come through to collect into drops, they were considered to be porous, but not permeable.



Section of Metal Collar with Concrete Disc

Figure 2.

The conclusions which they reached were:

First—In plain mortars, permeability depends upon the voids in the sand. A mortar not poorer than 1 cement to 2 sand will not leak, no matter what kind of sand is used. Mortars of 1 cement to 4 sand will be impermeable if made of a normal mixture of sand, that is, a sand having the normal variation in size of grains. Any mortar will become impermeable if the water acting against its face contains suspended matter.

Second.—Cement Coatings.—One quarter inch coating of neat cement will make mortar impermeable.

Third.—Soap and Alum.—Applications of soap and alum on very permeable mortars do not justify the expense. It is better to procure sand with less voids, or use a richer mortar. Soap and alum used in the mortar do not make it impermeable, at least from the beginning.

Work of Kettler and Sherman.—In 1901, Mr. F. C. Kettler and J. K. Sherman, students of the Ohio State University, continued the investigations upon the permeability of cement mortars, using varying percentages of water in mixing the mortars, and using loam in the sand. They also used grout washes on the surface to prevent permeability. The thickness of the mortar tested was 1½ inches. Their method of ramming and testing was the same as in the previous tests. Their experiments with loam did not show any definite results effected. Loam with standard sand was very permeable, less so with lake sand.

In the use of a varying quantity of water used in mixing the mortar, it was found that mortar of standard sand was quite permeable, the permeability decreasing as the percentage of water in the mortar increased from 8 to 14 per cent. The permeability of the lake sand mortar was

much less than with the quartz, but showed no regularity with variations in the use of water in the mortar. The lowest permeability with lake sand mortar was obtained when 14 to 16 per cent. of water was used in the mortar. The wetter mortar required less tamping and more mortar to fill the collar, thus indicating a denser mixture.

In testing grout washings, the clear mortar disc was first tested under pressure, then washed with a grout of one part cement and one part water, allowed to set 24 hours and placed under pressure. Another washing was applied, the disc allowed to set 24 hours and tested again. According to the tests the first wash was most beneficial.

The final conclusions were:

The permeability of mortar depends upon—

1st. The ratio of sand to cement.
2nd. The voids in the sand.
3rd. The percentage of water used in making the mortar.
4th. The thickness of mortar.
5th. The head of water pressure.
6th. The amount of tamping.

The permeability can not be materially reduced by the application of soap and alum solutions, or by finely powdered loam used in the sand.

Permeability can be reduced—

1st. By the application of 1 to 5 coats of cement grout, the reduction amounting to from 70 to 98 per cent. of the initial leakage.
2nd. By a coating of neat cement mortar ¼ inch thick.
3rd. By the mortar surface standing under a head of water containing suspended matter.

LOAMY SAND.

The majority of engineers specify that the sand shall be clean and sharp. A series of tests carried on at the Ohio State University under the direction of Prof. C. E. Sherman, also the results obtained by a class in cement testing under the writer, seems to prove that clay or loam up to 15 per cent. of the weight of the sand adds strength to the mortar. If additional tests under the varied conditions arising in practice continue to prove satisfactory, this will mean a great economy in many pieces of work where bank sand can be substituted for lake or washed sand.

The series of tests referred to were carried on during the winters of 1901, 1902 and 1903, by eight students of the Ohio State University, grouped two and two in investigations upon the effect of clay and loam in sand upon cement mortar. Each thesis embraced the results of such tests with Dyckerhoff cement and some standard American Portland. The mortar was made of 1 part cement and 3 parts sand, a definite percentage of

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the sand being clay or loam. Each thesis included three series of tests, one with standard quartz sand, one with lake sand, and one with equal proportions of the two mixed. In each series, separate tests were made with clay and with loam, used in the following proportions by weight of the sand, namely, 2, 4, 6, 8, 10, 12 and 15 per cent. A total of about ten thousand briquettes were broken. The same conclusions were reached in each of the four theses written, namely, that either clay or loam added to sand up to the limit of 15 per cent. by weight, did not have any injurious effect upon Portland cement mortar after the first two weeks and up to the limit of time which the tests covered, namely, 12 weeks.

On the contrary the clay and loam added considerably to the strength of the mortar. The results differed with different cements, and with the different sands. Their conclusions were that the chemical composition of the cement influenced the results to some degree. In some cases 10 per cent. seemed to give maximum results, but the majority of the tests showed that 15 per cent. of clay or loam gave the greatest strength. Clay uniformly gave higher results than loam. One detrimental result was definitely established, that mortars made from sand carrying clay or loam could not be placed under water safely, in less than 48 hours after mixing, because the loam softened and warped under the influence of water.

Thus, for subaqueous masonry it would be unsafe to use sand containing clay or loam in mortar. There is one plausible explanation for the increased strength obtained and that is in the addition of smaller particles of material which aid in filling up the voids in the sand. If 10 or 15 per cent. of fine sand was added to the ordinary standard quartz it would undoubtedly give stronger results than with the clear crushed quartz.

Before finally accepting these tests as conclusive, it would seem best to submit a series of briquettes to a long time test of at least two years, allowing them to weather and freeze under conditions similar to those to which actual structures would be submitted.

Work of Chubb and Chaffin.—Since writing the foregoing paragraphs upon the effects of loam and clay upon cement mortars, Messrs. J. H. Chubb and W. W. Chaffin, civil engineering students in the class of 1904, of the Ohio State University, have carried on another extensive set of tests under the writer's direction, upon loam in cement mortars, noting particularly the effect of weathering and temperature upon such mortars. They also carried the percentages of loam used up to 27 per cent. of the weight of the sand. The percentages of loam used were 10, 15, 18, 21, 24 and 27 per cent. by weight of the sand used in the mortar.

The cements used were Giant and Atlas. The sands used were standard, lake and bank sand. The loam used was the ordinary clay field loam from the university campus, dried and sifted through a number 40 sieve. The mortars were all made of 1 part of cement to 3 parts of sand by weight, the loam being a percentage of the 3 parts of sand. In

mixing the mortar, the water varied according to the loam used, but the mortar was kept as nearly as possible at the same consistency.

To obtain the effect of weathering, 10 briquettes were made at one time and alternate briquettes were selected and subjected to the outdoor conditions. All the briquettes were kept in moist air for 48 hours and then the outdoor set of 5 briquettes was put in an exposed place with about one or two inches of loose earth thrown over them, while the indoor set was placed in pans of water. They were allowed thus to remain until broken, the outside set being exposed to all kinds of weather. The tests were carried on over a period of 8 months.

The following conclusions were reached:

1. The curves from the plotted results plainly show that conclusions drawn from tests three months of age would not always safely hold for longer period tests.

2. The mortars containing the highest percentages of loam weathered better than the clean sand mortar and the mortars containing the lower percentages of loam. The curves, for similar mortars which were kept outside and inside, did not harmonize at all for the lower percentages of loam used, but for the higher percentages of loam, the curves paralleled each other, the outside stored mortars being slightly lower in strength up to the 8 month period, but gradually approaching each other as their age increased.

The deduction was, that the higher density of the mortars with larger percentages of loam prevented the rapid absorption of water and the consequent damage to the briquettes by freezing and thawing.

3. A cement mortar containing large percentages of loam will not reach its ultimate strength as quickly as one containing little or no loam.

The rate of increase in strength, however, becomes greater for large percentages of loam, over low percentages, as the age increases, at least up to the 8 months limit.

If a mortar is to be used in a structure which is to be immediately subjected to great stress, a sand should be used which does not contain more than 10 per cent. of loam. As ordinary bank sand does not contain more than 7 or 8 per cent. of loam it is quite safe to use bank sand for such buildings.

4. If the mortar is to be used under water, clean sand should be used.

5. Mortars exposed to the weather gain strength slower than those placed under water, but ultimately they attain equal strength.

The deduction was made, that mortar placed outside was frozen part of the time and was dependent upon the thawing and rains for the necessary amount of additional water for hardening which the briquettes on the inside could get at once.

6. The variations in the size of the grains of sand, or the percentage of voids, determines the amount of loam which can be added.

Comparing the sands used, the conclusion was, that the difference in strength shown by the several mixtures was due, largely, to the resulting density of the mortars.

7. The writer came to the conclusion after carefully weighing the evidence of the diagrams, that a mortar with 24 per cent. of loam in the sand is about the highest safe limit for Giant cement, while about 21 to 24 per cent. is the limit for Atlas cement.

The temperature diagram shows that the minimum temperature during the day was below freezing during most of the time of the first four months of the tests, while the maximum temperature was below freezing 58 days out of 90.

The precipitation was slightly above normal.

COLORED MORTARS.

Colored mortars are used for various purposes. Mortar for pointing is colored to match the brick or stone masonry or else in contrast to set the joint in relief. Concrete building stones are colored red, terra cotta, brown, or slate to resemble different natural building stones. Cement sidewalk surfaces are colored slate, black or brown to prevent the glare of light which the uncolored cement surfaces reflect. Physicians have claimed that the great prevalence of ophthalmia and other forms of weak eyes is frequently due to the blinding glare from cement paved walks and limestone paved roads. At any rate, it is well known that uncolored pavements are very taxing on the eyes during bright, clear weather.

Mosaic and tile work are now manufactured from cement by using certain coloring materials. The cement sets very hard and permits a high polish. No coloring containing acids or anything that will act upon the alkalies in the cement can be used. Vegetable or oil colors destroy or impair the strength of the cement. Dry mineral colors affect cement the least, although, with the exception of ultramarine, which contains much silica, all coloring materials reduce the strength and durability of cement mortar to a greater or less degree. Ultramarine in small quantities seems to strengthen the mortar slightly.

The iron oxides and ochres are used for all shades ranging from yellow to red and brown; Manganese dioxide and lamp-black for grays, slates and blacks; and ultramarines for the greens and blues. Manganese dioxide is better for slates and blacks than lamp-black, as the oil in the latter affects the strength of the mortar.

Several tables giving the materials to use for different colors with the proportions to be used are condensed and given below. Column number one is taken from a leaflet on Portland cement by the Buckeye Portland Cement Company; number two is taken from C. C. Brown's

"Directory of American Cement Industries;" and number three is taken from Professor I. O. Baker's "Roads and Pavements." They seem to have the same general origin.

TABLE 7.

Materials used in Coloring Mortars.

Color.	Mineral.	Pounds of Color to 100 Pounds Cement.		Pounds Color to Barrels Cement.
		1	2	3
Gray	Germantown Lamp Black	¼	½	2
Black	Manganese Dioxide	12		48
Black	Excelsior Carbon Black		2	
Blue	Ultramarine	5	5 to 6	20
Green	Ultramarine Green	6	6	24
Red	Iron Oxide	6	6 to 10	24
Bright Red	Pompeian or English Red	6	6	24
Sandstone Red	Purple Oxide of Iron	6		24
Violet	Violet Oxide of Iron	6		24
Brown	Roasted Iron Oxide or Brown Ochre	6	6	24
Yellow or Buff	Yellow Ochre	6	6 to 10	24
White	Lime, White Sand and Marble, also a Mixture of Lead and Zinc Salts with Calc Spar will give very light surfaces.			

The color is mixed in various ways. In concrete walks it is sometimes sprinkled on the top and troweled into the surface. This does not give an even color nor does it last as well as when thoroughly incorporated with the sand and cement. It is sometimes added to the sand and thoroughly mixed dry, then the cement and finally the water is added. The best method is to mix the coloring matter and cement dry, and use it thereafter as so much cement. Strength is gained and expense saved by using the colored cement for the surface coating only, not exceeding one inch in depth with the colored mortar used.

The effects in the red and brown sandstones are imitated so perfectly that it requires close inspection to detect the artificial from the natural stone. The artificial stone, however, is more durable and stronger than the natural stone.

HAIR CRACKS OR SUN CRACKS.

The surface of concrete sidewalks, and the smooth finished surfaces of other cement or concrete structures, frequently exhibit a network of fine cracks variously called sun-cracks, hair-cracks, veins and crazed work.

There appears to be a variety of opinions as to the cause of these veins or cracks. A summary of the answers received to the question "What causes sun-cracks or hair-cracks?" may not be out of place. These answers were received from experienced cement workers, engineers and cement manufacturers. Twelve gave as a reason, that the surface coating was too rich in cement. One, that too fine sand caused the trouble, bringing too much cement to the surface. Three, that over troweling was

to blame, and one or two of these said that the troweling brought an excess of cement to the surface. Three said that it was caused by troweling after initial set. Two that rapid evaporation or drying out of the surface caused the cracks. One claimed that hydration of free lime and the absorption of carbon dioxide caused the fine rupturing of the surface. One man said that "if the surface be troweled hard just at beginning of initial set, until all the water is taken up, there will be no hair-cracks."

Fig. 3.—Parapet of the Y Bridge at Zanesville, Ohio, Showing Hair Cracks and Surface Corrosion.

A translation from L. Gollinellis* says: "Hair-cracks appear as fine lines on cement work which has stood some time. They are especially to be noticed on cement which has lain in the open air, and are due to frequent changes between wet and dry conditions. Hair-cracks and shrinkage cracks occur chiefly when pure cement, or mortar too rich in cement, is used. They may be certainly avoided by the use of sufficient sand and suitable treatment of the work."

Mr. W. D. Lober, Secretary of the Vulcanite Portland Cement Company of Philadelphia, says of smooth finished concrete work: "The troweling brings the water to the surface and also the fine particles of cement which are carried with the water and makes the surface practically neat

*Das Kleine Cement-Buch. *Eng Record*, May 12 and June 2, 1900.

cement. If the surface is left in the wet condition and not protected from air and sun, it will dry out very quickly and in common with other materials in a moist state when drying in this manner it will crack."

Figure 3 shows the initial appearance of hair-cracks as illustrated upon the parapets and corner posts of the Y bridge at Zanesville. Figure 4

Fig. 4.—Concrete Steps, Showing Developed Hair Cracks.

shows the approaching dissolution of some concrete steps affected with hair-cracks. These steps have been down twenty-two months.

As the fine sand and over-troweling both develop an excess of cement at the surface, there are really 16 answers favoring over-rich mortar as the cause, with 6 answers scattered between troweling after initial set, rapid drying, and the after hydration of excess free lime.

It has been the writer's opinion based upon several years of observation both of the construction and the wear of cement walks, that such cracks are caused by the expansion and contraction of the immediate

surface where it is composed of a mortar too rich in cement. In some cases this effect has been particularly aggravated by troweling more cement to the surface. The neat cement film has a different coefficient of contraction than the mortar of sand and cement and causes fine cracks on the surface in setting. This effect is seldom seen in surfaces where coarse sand has been used. One very successful walk builder in Peoria, Illinois, said that while specifications usually called for a top coat of 1 cement to 1 sand, he could do better work with a mortar of 1 cement to 1½ or 2 sand, usually using a 1 to 1½ mortar. He has the reputation of being one of the safest and best walk builders in Central Illinois.

In and around Chicago the specifications for cement walks usually call for the top coating to be of one part Portland cement and one part of clean coarse sand or torpedo gravel, which is a fine uniform gravel, slightly coarser than the standard crushed quartz used in cement laboratory tests. The walks, as a rule, around Chicago, are durable, well made walks, and seldom show veins or sun cracks.

The concrete walks in the Ohio State University campus show veins in many places and the writer has been watching their development for over two years. At first, fine hair-cracks appeared upon the surface of the walks, then after some time a deposit of brownish or slate colored material appeared along the hair-cracks and the cracks were more marked, became wider and more continuous. The deposit became from ⅛ to ¼ inch in width and of appreciable thickness. After two or more years the cracks open much more rapidly, as the frost seems to obtain better leverage.

Samples of this brown deposit were analyzed for the writer by Mr. A. V. Bleininger, chemist in the Department of Ceramics, with the following results:

	Per cents.
Soluble matter	7.61
Silica	33.06
Alumina	3.68
Calcium Oxide	37.98
Magnesium Oxide	7.02
Losses, black organic matter—sulphur, alkalies, etc.	10.65
Total	100.00

The soluble matter analyzed as follows:

	Per cents.
Alumina	1.07
Calcium Oxide	1.84
Magnesium Oxide	0.06
Alkalies, etc.	4.64
Total	7.61

The mortar in the concrete next the veins was analyzed and showed,

	Per cents.
Magnesium Oxide	1.15
Sulphuric Anhydride	1.53

The results show a high content of magnesium and calcium sulphates, both of which are injurious to concrete.

Mr. Bleininger says that the water leaching through the concrete brings to the fine hair-cracks these soluble alkalies, calcium and magnesium sulphates, and they are deposited along the cracks upon evaporation, together with other chemicals which form insoluble compounds The leaching process opens the concrete for still further leaching and the concentration of the chemicals induces greater changes and thus the damage increases.

Of course in winter the water, freezing in the cracks, expands them, and the stone having been weakened by the leaching chemicals is ready to go to pieces. The organic salts and sulphuric acid aid greatly the solubility of the mortar materials and these chemicals may be greatly augmented from the soil and particularly from the cinder foundations.

Poorly tamped or porous concrete will also be more easily attacked in this manner.

LIME IN CEMENT MORTAR.

Lime is frequently used in cement mortar for various reasons. Masons claim that cement mortar works harsh and brittle, and that the addition of lime paste to the mortar "gives it body" and makes it "work smoothly" under the trowel. Lime paste is frequently added to cement mortar to cheapen it; the claim being made that lime paste up to 25 per cent. of the cementitious material used may be added without perceptibly weakening the mortar. General Gilmore says that lime paste equivalent to one-half or three-fourths of the volume of cement may be used without producing serious deterioration in the mortar. Lime paste is frequently added to cement mortar to make it impervious. Others have added 10 to 20 per cent. of cement to lime mortar in order to strengthen it.

In 1891, the writer carried on a series of tests to prove some of these claims for lime-cement mortars. The tests were carefully made in the laboratory of the University of Illinois and covered a period of five months. The mortar used was composed of one part cement to two parts of clean coarse sand of standard sized grains. The cement was composed of various parts of lime and a natural cement, ranging from all natural cement to all lime paste. A parallel set of tests was also conducted with Portland cement and lime. The tests were made to find the adhesive and cohesive strength of such mortars and compare them with the tensile strength ordinarily found by making the mortar into briquettes and breaking them. Bricks were laid crosswise to each other and cemented together with these mortars and their strength or resistance to breaking apart was obtained. Eight hundred of these adhesive tests and 160 of the ordinary tensile tests were made with each kind of cement. Table number 8 shows the proportions of lime, cement and sand used in parts by volume.

TABLE No. 8.

Proportion of Lime, Cement and Sand Used in Mortars.

Ref. No.	Lime Paste, in Parts.	Cements, in Parts.	Sand, in Parts.
1	0	10	20
2	1	9	20
3	2	8	20
4	4	6	20
5	6	4	20
6	8	2	20
7	9	1	20
8	10	0	20

TABLE NO. 9.

Adhesion Between Mortar and Brick.

	Composition of Cementitious Material.							
Cement, per cents of	100	90	80	60	40	20	10	00
Lime paste, per cents of	00	10	20	40	60	80	90	100
Order of Making.	5	6	4	2	1	3	7	8
Age in Days.	Pounds Per Square Inch.							
1	6.1	3.1	2.9	4.0	3.6	2.6	2.7	2.0
2	7.4	9.3	4.5	5.1	3.5	2.9	3.5	2.6
3	6.7	10.1	4.6	4.4	5.0	2.5	1.9	2.9
4	8.5	11.4	5.0	5.6	5.7	3.7	2.6	2.6
5	7.4	15.1	5.8	5.9	6.5	2.9	3.7	1.9
6	....	16.0	5.1	7.0	6.6	3.6	3.1	2.3
7	8.4	16.9	5.2	7.1	7.0	3.6	3.1	2.3
14	19.4	21.5	12.0	8.8	9.0	6.3	4.4	5.2
21	20.0	24.5	22.9	12.5	8.3	8.0	6.3	5.8
28	27.1	24.4	23.6	15.2	8.7	8.9	6.9	7.3
35	30.5	26.4	28.7	15.5	16.9	10.7	6.4	10.1
42	35.7	31.3	27.6	15.1	9.5	8.1	8.5	12.1
49	36.2	35.8	32.9	16.2	13.2	7.5	7.6	13.9
56	33.3	31.2	38.2	21.7	13.4	9.0	10.8	15.2
63	40.5	38.4	35.1	24.8	16.5	11.6	11.5	.....
91	42.0	41.5	35.9	22.3	21.5	10.7	11.1	12.2
119	44.7	39.1	43.9	22.6	15.1	12.6	11.7	.....
147	47.2	51.3	36.8	25.0	15.7	10.4	.....	.....

Table No. 9 shows the results for adhesion with the natural cement for ages varying from one day to five months.

Diagram No. 1 shows the same clearly in a graphical form.

Diagram No. 2 presents the same in still another form.

Table No. 10 shows the cement, sand and lime used in pounds, with the cost of the lime and cement.

DIAGRAM 1

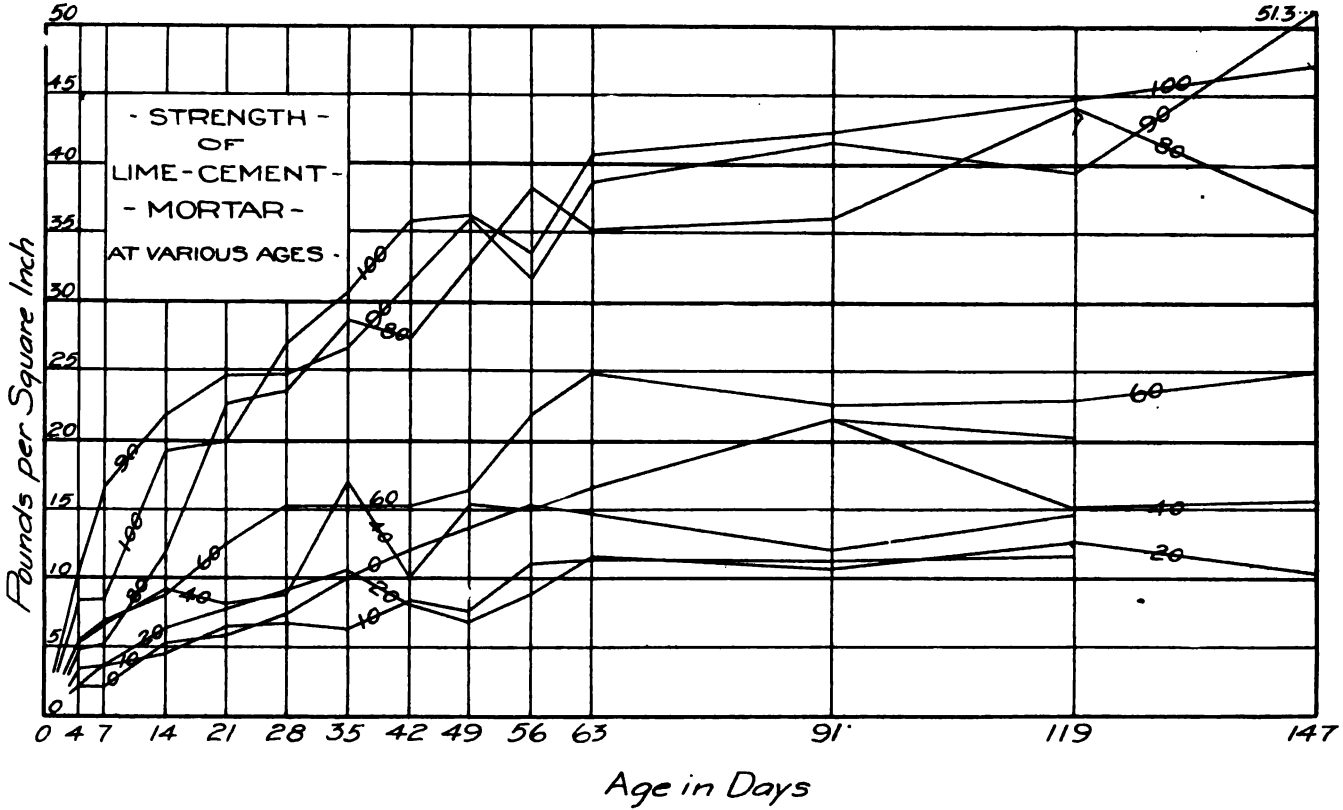

- STRENGTH -
OF
LIME-CEMENT-
- MORTAR -
AT VARIOUS AGES -
Pounds per Square Inch
Age in Days
0 4 7 14 21 28 35 42 49 56 63 91 119 147
0 5 10 15 20 25 30 35 40 45 50
513
100
90
80
60
40
20
0

DIAGRAM 2

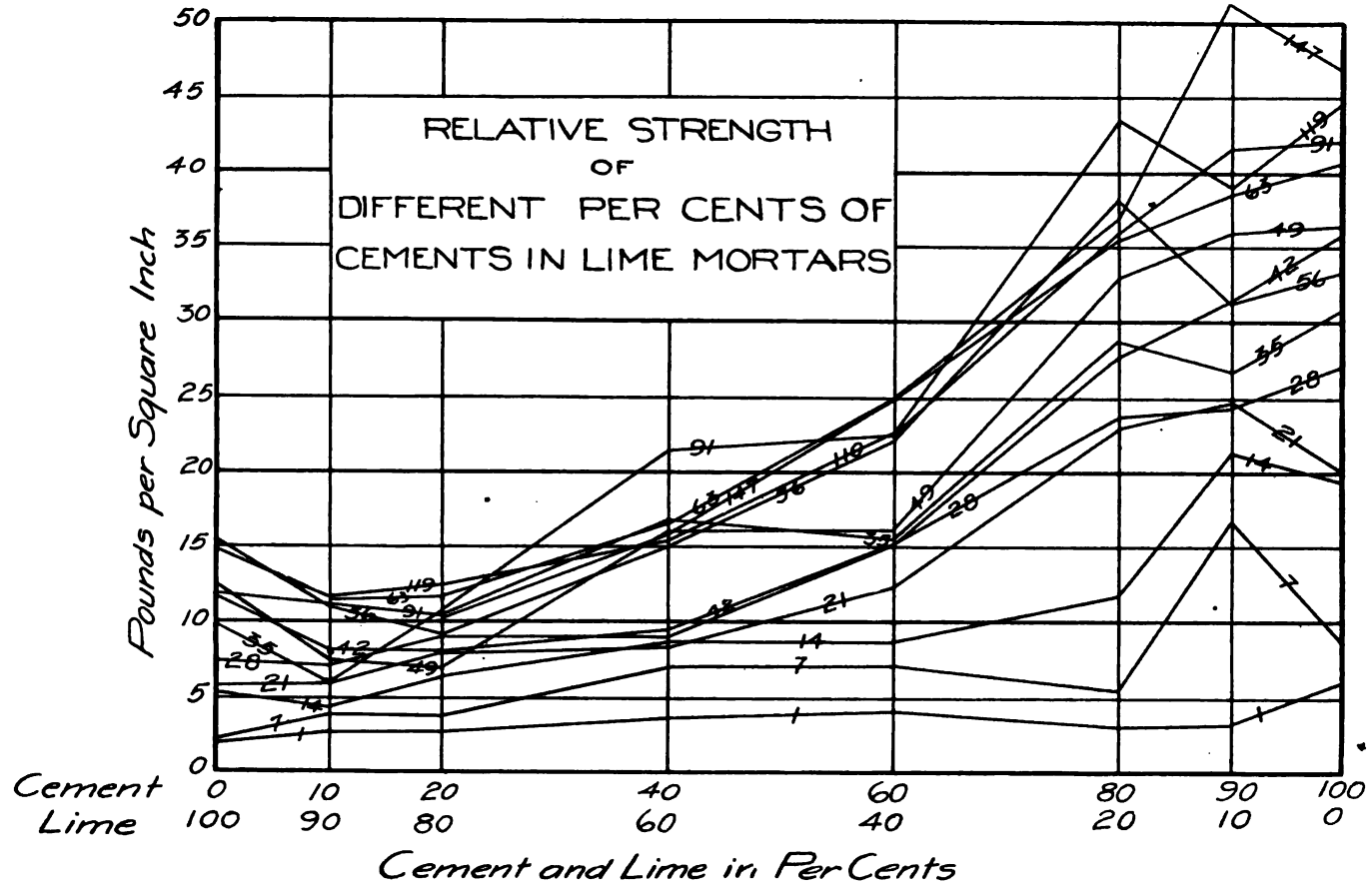

RELATIVE STRENGTH
OF
DIFFERENT PER CENTS OF
CEMENTS IN LIME MORTARS
Pounds per Square Inch
50
45
40
35
30
25
20
15
10
5
0
Cement
Lime
0 10 20 40 60 80 90 100
100 90 80 60 40 20 10 0
Cement and Lime in Per Cents

TABLE No. 10.

Proportions of Sand, Cement, Lime, and Water in Pounds with the Cost of the Lime and Cement. Proportions by Volume.

Pounds of				Total weight of Water.	Values given in Cents.			
					Cost of		Amount saved.	
Sand.	Cement.	Lime.	Water in Mortar.		Lime.	Cement.	Total.	Per Pound of Cement.
9	2.85	.00	2.31	2.31	.000	1.075	.000	.000
9	2.56	.41	2.17	2.47	.029	0.968	.078	.027
9	2.27	.83	1.75	2.36	.057	.860	.158	.055
9	1.70	1.74	1.21	2.44	.115	.645	.315	.110
9	1.14	2.47	.92	2.68	.172	.330	.573	.201
9	.57	3.29	.25	2.60	.229	.215	.631	.221
9	.28	3.71	.20	2.85	.258	.107	.710	.249
9	.00	4.12	.00	2.92	.287	000	.788	.276

The conclusions reached were, first, that 10 or 20 per cent. of lime paste added to cement mortar did not materially affect its strength, but cheapened it from 2½ to 5 per cent. of the cost of the cement. Second, that any greater per cent. of lime paste added, rapidly decreased the strength of the mortar without an adequate reduction in the cost. Third, that adding 10 or 20 per cent. of cement to lime mortar weakened instead of strengthened the mortar and increased the cost. The investigation also indicated that the addition of a small percentage of lime paste to cement mortar, or of cement to lime mortar, did reduce the harshness of the mortar in the one case and the stickiness of the mortar in the other, causing it to work much easier under the trowel, and from that point of view was a benefit to the mason.

TABLE No. 11.

Relative Strength of Mortars in Briquettes and in Joints.

Mortar Composed of 2 parts Sand and 1 part Cement and Lime Paste.		Age in Days.	Cohesion in Pounds per Square Inch.		
			Stored in		
Composition of the Paste.			Air.		Water.
Per cent. of Cement.	Per cent. of Lime Paste.		Between Brick.	In Briquettes.	In Briquettes.
100	00	7	9.9	29.6	10.1
100	00	28	27.1	38.6	49.3
100	00	35	30.5	40.7	23.4
100	00	63	40.5	....	
100	00	77	....	34.7	109.7
80	20	42	19.1	27.8	65.1
40	60	28	8.7	15.6	
10	90	28	6.9	15.1	....

The comparison between the mortar placed between the bricks in as nearly the same manner as a mason would lay brick masonry and the mortar molded into briquettes is shown in table number 11.

A similar series of tests upon the same cements mixed with lime paste, the mortar being formed by using the materials in proportions by weight instead of volume, is now being carried on by students of the Ohio State University. So far as the tests have proceeded they seem to corroborate the tests given above.

PLASTER.

An important use for cement mortar is in the form of plastering or coating surfaces such as the impervious coatings for retaining water in cisterns, reservoirs and tanks, or the outer coating used to prevent water entering sub-surface areas as in basements, manholes and conduits. It is also used upon the exterior surfaces to protect them from the destructive influences of the elements, and upon the inner walls and ceilings of houses to give a hard, smooth finish. Care should be exercised to proportion the sand and the cement so that the mortar shall be impervious by having all the voids filled. A Portland cement is best for this purpose. Its proportions should be about one part cement and one and three-quarters to two and one-half parts of clean sand, the proportion varying according to the voids contained in the sand.

The Buckeye Portland Cement Company publish the following:

"For water tight work, as cisterns, etc., in coats ¾ of an inch thick, the following proportions of Portland cement-lime-mortar can be used with safety and economy."

TABLE 12.

Proportions in Portland Cement-Lime-Mortar.

Portland Cement.	Sand.	Lime Paste.
1 part	2 parts	0.5 part
1 "	3 "	1.0 "
1 "	5 "	1.5 "
1 "	6 "	2.0 "

"Mortar made with five or six parts sand to one of Buckeye Portland cement is good enough as far as strength is concerned, but is then too 'poor,' 'short' or 'brash,' and does not adhere sufficiently to the stone and brick.

"The addition of slacked lime in small proportions makes the mortar 'fat,' 'rich' and pleasant to work.

"It greatly increases its adhesiveness and density, and, contrary to general belief, also adds to the strength of all such mixtures.

"Any greater or any less proportion of lime to the mixture given will lessen the density, the tensile strength, the crushing strength and the adhesiveness. This lime paste or slacked lime is more than half water.

TABLE 13.

Table of Proper Proportions for Ordinary Purposes.

Portland Cement.	Sand.	Lime Paste.
1 part	5 parts	0.5 part
1 "	6 "	1.0 "
1 "	8 "	1.5 "
1 "	10 "	2.0 "

TABLE 14.

Amount of Sand, Portland Cement and Lime Putty Needed to Lay 1,000 Bricks.

Joint.	Proportion of Mortar to the Brick.	Bushels of Sand.	Bushels of Cement.	Bushels of Lime.
⅛ in.	1-9	3.8	.64	.64
¼ "	1-4	9.6	1.6	1 6
⅜ "	3-10	12 5	2.1	2.1
½ "	1-3	15.2	2.5	2.5

"Three and one-third bushels of Buckeye Portland cement in each barrel.

"One barrel of above described Buckeye Portland cement mortar will lay 2,000 bricks with ¼ inch joints."

The following is taken from the "Directory of American Cement Industries."

TABLE 15.

Volume of Mortar in a cubic yard of Masonry.

	Cu. Yds.
"For brick work, ⅛ inch joints	0.15
For brick work, ¼ inch joints	0.25
For brick work, ½ inch joints	0.40
For ashlar, 20-inch courses	0.06
For squared stone masonry	0.20
For rubble masonry	0.25
For concrete, broken stone	0.55"

Mr. F. P. Van Hook, in an article in Municipal Engineering Magazine telling how to prepare a Portland cement wall plaster, says:

"Portland cement mortar should be made as follows: Take good double strength lime, and slake in plenty of water. Do not stir the lime only enough to keep the large lumps from burning. It should stand a week or ten days before using. Put in 2½ bushels of good clean hair to two barrels of lime; when ready to commence plastering, take one barrel of a good standard

brand of American Portland cement to three barrels of lime. First, mix the Portland cement with four parts of sand, mixing the sand and cement thoroughly. Second, the lime mortar should be sanded to the right consistency to make a good, rich mortar. Third, mix the sanded cement with the lime mortar as it is used. It will take a very little mixing to make a fine tough mortar."

CEMENT STUCCO FOR WALLS.

Mr. Van Hook also gives the following instructions for cement stucco:

"First coat, one-half inch thick. For best results, the wall should be furred off with spruce lath put on vertically, 12 inches apart and well nailed. On these fasten firmly, expanded metal lath. Add fibre to the mortar for lathwork. Wet thoroughly the surface to be plastered. Mix one part of non-staining Portland cement with two parts medium sand, one part fine sand and one-half part lime flour. When this coat has set hard, wet the surface thoroughly and apply the second coat with a wooden float.

"Second coat, one-quarter inch thick. Mix one part cement as above, one part fine sand and two parts medium sand or crushed granite. Before the second coat has set hard, it may be jointed to present the appearance of stone work. A small addition of lime flour increases the adhesion of the mortar.

"The finished surface should be protected for at least two weeks with canvass curtains or bagging saturated with water.

"Defects are liable to appear on cement plastered walls when (1) too much cement is used; (2) not applied with sufficient moisture; (3) not troweled sufficiently; (4) not protected from variations in temperature and drafts of air."

Cement manufacturers publish the following table of areas covered with Portland cement mortars of various proportions per barrel of Portland cement used:

TABLE 16.

Showing Area Covered by Mortar Produced from One Barrel Portland Cement.

Composition of Mortar.	Thickness of Coat.	Sq. Ft. of Area Covered.
1 Cement 1 Sand	1 inch	67
	¾ "	90
	½ "	134
1 Cement 2 Sand	1 "	104
	¾ "	139
	½ "	208
1 Cement 3 Sand	1 "	140
	¾ "	187
	½ "	280

The Buckeye Portland Cement Company print a useful table showing various data in reference to plastering cisterns, which table is here inserted:

TABLE 17.

Showing Capacity, Quantities of Excavation, Stone and Brick Lining and Plastering in Cisterns of various diameters, for each foot of depth. Also number of bricks and amount of plastering in bottom.

Diameter in feet.	For Each Foot Depth.					Bottom.	
	Capacity (gallons).	For this Column use diam dig'g.	For these Columns Use Diameter in Clear of Lining.			Use diam. of digging.	Use diam. in clear of Lining.
	For each ft. depth.	Cub. yds. of digging.	Stone lin'g 1 foot thick, 25 cub. ft.	No. bricks in lining—one thick.	Sqr. yards plastering.	Bricks in Bottom.	Plastering in bottom square yds.
5	146	.73	.75	230	1.74	148	2.18
6	211	1.04	.88	275	2.09	215	3.14
7	288	1.42	1.00	320	2.44	292	4.27
8	377	1.86	1.13	365	2.79	382	5.58
9	476	2.36	1.26	410	3.14	483	7.06
10	587	2 91	1.38	460	3.49	596	8.72
11	710	3.52	1.51	500	3.84	722	10.56
12	846	4.19	1.63	550	4.19	859	12.56
13	992	4.92	1.76	590	4.54	1008	14.74
14	1152	5.70	1.88	640	4.89	1170	17.10
15	1325	6.54	2.01	680	5.24	1343	19.63

For the number of hundred pounds of cement needed for a half inch plaster coat, divide the square yards by 15 if half cement and half sand or 25 if a third cement and two-thirds sand.

CONCRETE MOLDINGS AND BASE-BOARDS.

In the Alexian Brothers' Hospital, Chicago, * marble concrete, called "art marble," is used for the floors, base moldings and stairway treads and risers. No wood or plaster was used within 6 inches of the floors. All base moldings were made continuous around corners and at door openings. All exposed angles were rounded and the marble surfaces polished.

The tread and riser for each step was made in one piece. The foot of each riser was recessed into the top of the next lower tread so as to make but one tightly fitting joint for each step. Figure 5 shows the method of construction. Such sanitary construction should be a part of all public buildings, but especially those used for hospital purposes.

Eng. Record, Feb. 3, 1900.

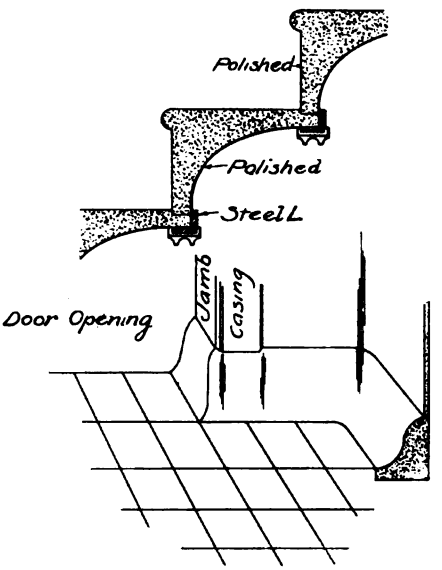


Fig. 5.—Illustrated Use of Stairway and Baseboard, Alexian Bros.' Hospital, Chicago, Ill.

FILLERS.

Cement mortar or grout, a very thin liquid mixture of cement, sand and water, is frequently used to fill the joints in street paving. "Murphy's Grout Filler" was among the first so used. This is a patented mixture of Portland cement, ground slag and sand; the claim is made that the slag gives both strength and impermeability to the mortar.

Portland cement two parts, with fine sand one part mixed with sufficient water to make a fluid grout, makes a good filler for both brick and wood paved streets. Such a filler is impervious, durable, and gives good support to the blocks. The strongest objection to its use with brick pavements is its unyielding character which does not allow for expansion. Frequently in hot weather, when expansion takes place, in brick paved streets having grout filling, the pavement will arch away from the foundation, causing the streets to rumble under traffic. Because the bricks are unsupported except by arch action, they are apt to yield under heavy traffic and long cracks or ruts appear in the street allowing water to reach the foundations, thus quickly destroying the pavement. This danger can be prevented, however, by putting in longitudinal and transverse expansion joints of asphaltic or coal tar cements.

GROUTING.

Mr. Wm. J. McAlpine* says in substance, long experience proves that tight work can only be made in grouting masonry when neat cement

*Eng. News, April 17, 1902.

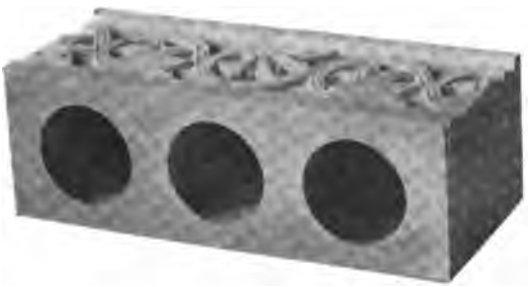


Fig. 6.—Ornamental Block of Litholite.

Fig. 7.—Ornamental Pieces Designed for a Library Building. Stevens' Cast Stone or Litholite.

is used. If sand is used with cement, it separates and settles, filling and blocking the channels, and preventing the cement from reaching the lower cavities in the masonry. The result is that the lower portion of the masonry has many unfilled voids, then comes a layer having the interstices filled with sand and the top layer is filled with neat or nearly neat cement grout.

Nearly forty years ago a commission of Government Engineers of whom Major R. E. Lee was one, built a wall and carefully grouted it with sand and cement grout. When the wall was torn down the results claimed by Mr. McAlpine were substantiated.

ORNAMENTAL WORK.

For many years in Europe, and for the last few years in this country, the use of cement mortar for ornamental work such as ceiling and wall panels, capitals, gargoyles, bases, stucco work, mosaic and tile work has been rapidly increasing. Such work is as lasting as cut stone, and far cheaper, because cast iron or wooden molds can be used over and over again in producing panel work or duplicate parts. Molding sand is also used for the forms.

Portland cement castings are much more durable than many of the building stones, and are much easier repaired in case of damage. Fire practically makes no impression upon them, while most natural stones would be completely destroyed by the combined effects of fire and water.

The mortar for this class of work should be composed of one part Portland cement and two parts of sand graded in size of grains, so that the voids in the sand would be proportionately small, and an even grain result in the artificial stone thus manufactured.

The Stevens Cast-Stone Company, of Chicago, manufacture an artificial stone called Litholite, illustrations of which will furnish an idea of what can be done in cement casting. One form of this stone is made by crushing any natural stone to granular form, mixing it with Portland cement and as explained by Mr. Stevens himself,

"by mixing materials so thin that we are able to run it through a rubber hose into the molds, we have produced a stone that meets the approval of architects and builders. Now, if we had no way of getting rid of this surplus water, we could not produce a first-class article, but we cast it in a porous mold, allowing the surplus water to be absorbed into the mold before initial set takes place. To produce a perfect crystallization, the stone should have more water as soon as the initial set has taken place. This is supplied through the porous mold, but at no time does the cement receive more water than is required for a perfect crystallization. Induration by absorption through a porous mold was so novel and new that we were cited to no patents with which we interfered."

"One of the worst problems has been to overcome the hair checking from appearing in cement work. To the best of our knowledge there are several causes for this hair checking. One cause is fresh cement, especially

if there is any free lime in it, other causes being the workmanship. Cement mixed not stronger than one to three or four of sand is not liable to hair check, and if the stone is well seasoned before exposing to the weather, it will not hair check."

In reference to the cost of the stone, Mr. Stevens, writes,

"We can get from one barrel of cement twenty-four pieces of stone 10 by 12 by 30 inches, or 60 lineal feet. With Portland cement selling at $2.40 per barrel, the cement in each block would cost ten cents; the other material being sand, gravel and crushed stone, the cost of these would depend entirely upon the locality."

He says that one man will make from 30 to 40 blocks per day of the size mentioned, and that with crushed stone at 85 cents per yard and sand and gravel at $1.25 per yard, they are making hollow trimmings, porch columns, etc., at 26 to 35 per cent. of the cost of natural stone work. His process for stone is shown by the sketch and patent explained below:

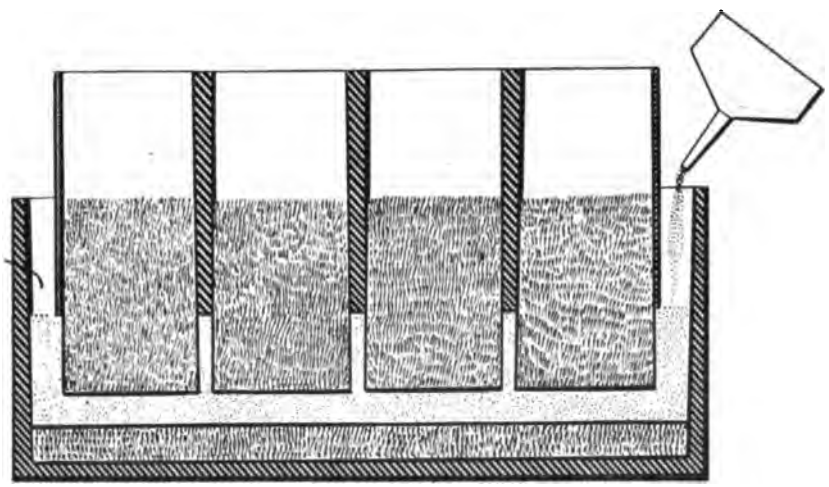


Fig. 8.—Illustrating the Method of Casting Litholite.

EXTRACT FROM PATENT SPECIFICATIONS.

Process of Making Artificial Stone. Charles W. Stevens, North Harvey, Ill. American Patent No. 699,588.

The process of making artificial stone, which consists in forming a mold containing a plurality of dry-sand cores, said cores being laterally supported by removable parting-boards and separated by parting-boards so disposed as to provide a space between the opposing faces of said parting-boards, in then pouring wet artificial-stone compound into said mold around and between said parting-boards, in withdrawing said parting-boards while the stone compound is still sufficiently plastic to flow into the space previously occupied by the parting-boards, and in then allowing the compound to set.

The illustration, Figure 9, shows a beautiful monument which Mr. Warren S. Cushman, the sculptor, designed and which was erected at Woodstock, Ohio, in memory of the soldiers and sailors of the Civil War.

Fig. 9.—Soldiers' Monument at Woodstock, Ohio; Weight 100 Tons, a Monolithic Cement Casting.

This monument is a monolith, cast where it stands from Buckeye Portland cement. It is 26 feet high and 14 feet square and weighs about 100 tons.

Mr. Cushman has made a careful study of Portland cement in connection with outdoor monumental work with a view of finding something more durable than marble and granite, and he believes that Portland cement fills his desires in that direction.

ROPE MOLDING.

Among other ornamental features, the Aberthaw Construction Co.. of Boston, now make a cast stone rope molding in two styles, smooth and rough finish. Like other ornamental designs this can be made in any color.

MOSAIC WORK.

For mosaic work, small colored pieces of encaustic tile, glass, marble, onyx, ornamental stones, or previously hardened pieces of colored cement are arranged in various patterns and cloth netting is glued or cemented over the face with some soluble cement. These flexible sheets of mosaic design called "Corded Ceramic Mosaic" are then ready for the bed stone of cement mortar. This bed plate is made of 1 part of Portland cement and 2 parts of sand, mixed quite wet. The sheet is then laid upon the fresh mortar and pressed down into it until the mortar has risen between the pieces up to the level of the sheet; the sheet is then soaked loose, the position of the pieces adjusted so as to secure uniform mortar joints and the plate is then allowed to set. The trimming of rough surfaces or polishing, if any is required, is done when the cement has hardened. The mosaic plate is then ready for use. When complete, it is about two inches thick.

Terrazo work is that form of mosaic which is made by setting in a ground of colored mortar, small irregular pieces of colored marble, glass, tile or granite. Or, the pieces may be mixed with the mortar and the surface ground and polished after the mortar has set. A central design may also be bordered in this irregular work.

TILES AND FIGURED WORK.

Floor tiles, rivaling in appearance and durability those made of burned clay are made from cement. Generally this is done under the protection of patents covering the press or dies or some feature of the process. A single tile may be of one solid color, or may be made of several different colored cements accurately disposed in geometrical or other forms. These different colors are prepared by grinding the cement, coloring material and fine sand intimately together, dry. They are then filled into a cellular or honey-comb die, each compartment of the die receiving its charge of the proper color by means of perforated cards or

Fig. 10.—Ball Room, Hotel Flanders, Philadelphia, Pa., Showing Ornamental Effects Produced with Woven Wire and Cement Plaster.

stencils which keep out all colors except the one being filled at the time. Each color requires its own stencil. When all the cells are charged, the comb is withdrawn gently, leaving the cement powder in little piles whose edges overlap one on the other. Without disturbing their positions, a mixture of coarse sand and cement, properly dampened, is now filled in on top of them until the die is full and stroked off level, when it is brought under a powerful press which compacts the loose material into a solid dense tile. The moisture from the damp backing penetrates and hydrates the dry cement composing the face so that in a day or so it has fully set. The tiles are placed on slabs of cement mixed with sawdust instead of sand; these are very porous and are kept damp so that they may furnish water as needed for the chemical process of setting the tile without softening its surface or causing the different colors to mix. In order to keep these colors clear and bright, and avoid the scum or whitewash, commonly found on cement surfaces, some chemical is generally used in the surface colors, or in the whole mass. This is generally kept secret, or patented, and is sold with the right to use the process. Magnesium fluoride is one of the best and commonest anti-scum chemicals in use for cements.

The tiles, when made and hardened, are used in laying floors exactly as clay tiles, being laid in a cement matrix or bed.

Imitation marble may be obtained by kneading and rolling together different colored mortars and pressing them into slabs which, after setting, can be ground and given a high degree of polish.

Figures 10 and 11 show what can be done with cement in ornamental lines.

FACINGS.

Cement mortar is used in facing concrete work. It is not put on as a plaster but the forms in which the concrete body is molded are so made that the outer surface, one to three inches in thickness, can be put in place and rammed at the same time as the body of concrete. This gives a smooth, finished appearance to the exterior and at the same time provides an impervious, durable surface. The mortar is usually made of one part cement to two or three parts of clean sand.

At first, the work was made of uniform texture throughout and the surface was coated with a plaster of neat cement, or of one part cement and one part fine sand. It was found, however, to be almost impossible to make a plaster coat permanently adhere to the body of the concrete mass which had become set before the plaster could be applied. The method of facing with mortar was then adopted. The latest practice, however, is to use a wet concrete in which all the voids are filled and which contains a slight excess of mortar. When the concrete is rammed, if a close tined fork with flat blades or a flat square backed shovel be forced down between the concrete mass and the form, it will force back

Fig. 11.—Main Corridor American Baptist Publishing Society Building, Philadelphia, Pa., Illustrating the Effect Obtained by Use of Cement With Furring and Wire Lathing.

the stone and coarse gravel and the excess of wet mortar will run next the form. Thus when the mass is set and the form removed the exterior will be smooth and waterproof. This method is cheaper than the two inch facing and equal in durability and appearance.

PROTECTION TO BRIDGE METAL.

Mr. J. M. Newhouse, carpenter foreman for the Columbus Terminal of the Pennsylvania railroad, has used Portland cement with oil and red lead to coat the metal work of the High Street Viaduct. A test section was coated early in 1900 and now after four years wear seems to be in excellent condition. Where it has been cut out for examination the metal is perfectly bright. The entire eastern section of the viaduct owned by the Big Four Railway Company was covered with this cement coating in 1900 and 1901 and is still in excellent condition. The outside of the eastern-most girder with the supporting posts show expansion cracks in the coating wherever the sun can strike the paint, but at no point does the coating seem to be loosened by this cracking. Upon cutting into the metal it does not appear to have sustained any corrosion. This coating was applied with trowels and is about ¼ of an inch thick. It required much care and time in spreading it, especially around the rivet heads. Small friction or troweling cracks would occur whenever hasty work was done. These cracks would have admitted water and allowed the rusting to proceed, therefore great care was used to put on a perfect coat. The steel work had been cleaned by the sand blast, and painted the year before, so that only hand cleaning was done before the mortar paint was applied. The cost of this coat, including the hand cleaning of the metal work and the cost of materials and applying them was eight cents per square foot.

The place is a particularly trying one on metal work, as the lower flanges of the girders are only about two feet above the smoke stacks of the passing engines. Practically all the traffic, passenger and freight, entering and leaving the Union station pass under this viaduct. Ordinary paints are cut out in a very short time and unprotected metal work soon corrodes through ¼ to ⅜ inch members. If this cement coat lasts as it promises to do, it will be well worth the additional cost. The officials said that it cost from one quarter to two-thirds more than the paints usually used. The life of ordinary paints is not much over three years, and under the trying conditions of this particular place would not probably exceed eighteen months to two years at the longest.

Mr. Newhouse gives the following directions for the cement coat:

12 pounds of red lead.
32 pounds of Portland cement.
2 pounds of Japan.

Add sufficient linseed oil to make, when thoroughly mixed, a soft putty like mixture. Apply with a trowel, upon thoroughly cleaned metal.

Mr. Newhouse is experimenting with other mixtures which he thinks will be even better than the one given above. One of the railway officials said that he believed this would be cheaper than paint because of the greater length of life.

LININGS IN WARSHIPS.*

Cement mortar is used in certain places both upon the inner and outer steel skins of warships, particularly where it would be difficult or impracticable to prevent corrosion by paint alone. Cement mortar is also used in corners to prevent water standing in them; when a small space is inaccessible for cleaning or painting, it is filled solidly with cement mortar.

The use of cement is restricted to the minimum possible, and if satisfactory paint could be found for all locations, this mortar would not be used at all for protection of metal. The usual proportions are, 1 cement, 2 sand. For all metal protection it is applied as thin as possible, never over 3 inches thick.

CEMENT HARDENED QUICK SAND.

Mr. Robert L. Harris, M. Am. Soc. C. E., patented in 1891, a device for hardening quicksand by means of cement grout injected into the sand. Those who have ever attempted to carry on excavation or construction of any kind in quicksand know how discouragingly expensive such work is. Mr. Harris' method is to drive pipes into the quicksand to the required depth and from four to eight feet apart, and then by attaching pumps to alternate pipes and pumping in water under pressure circulation is begun between these pipes and the ones left open. After circulation has been established and sufficient sand removed, cement grout is pumped in to take the place of the displaced sand. As soon as the grout appears in the open pipes they are capped and the pumps are run until a strong pressure is obtained to force the grout into the surrounding sand and then left to stand until the cement has time to set. The pipes are then raised a foot or more and the operation repeated. Some tests were made at Providence, R. I., which seemed to indicate that it would prove quite successful under favorable conditions. It was especially recommended for work in coarse sand or gravel, also as an aid to prevent large flows of water into trenches.

In erecting a bridge over the Danube at Ehingen, Bavaria, in 1898, the method of pumping grout into water bearing gravel was used very successfully. One and one-half inch pipes spaced about 18 inches to 20 inches apart were driven to bed rock and grout forced in under pressure, the pipes then drawn up and the operation repeated. Where the gravel did not contain large quantities of sand the grout was found to have pene-

*Information received from Mr. W. L. Capps, Chief Constructor, U. S. N.

trated several meters, but when the sand was compact there was no result. In the mid-stream piers, sheet piling was first driven for the coffer-dams and then grout was injected into the gravel surrounding the sheeting, resulting in a perfectly water tight coffer-dam. The interior of one of the coffer-dams was also treated in this manner and it was found upon excavation that wherever the sand was not in compact beds, hard, well bonded beds of concrete existed so that only part of the interior had to be excavated.

The same method was successfully employed upon two other bridges in Bavaria in 1898 and 1900.

THE EFFECTS OF FREEZING UPON MORTAR.

Experimental work * carried on in 1895 by students of the Ohio State University, indicated that in natural cement mortars, frost affected them in about the ratio that they contained magnesium oxide, but this did not prove to be the case with Portland cements. In natural cement mortars freezing disintegrated the exterior to a greater or less depth, materially weakening the mortar, while in Portland cement mortars disintegration did not appear and the loss of strength was very much less.

Baker and Symonds, of Thayer School of Civil Engineering, Dartmouth College, came to the following conclusions after having made 7,150 tests, that freezing does not disintegrate Portland cement mortar but does disintegrate Rosendale cement mortars; that while it seriously damages the natural cement mortars, Portland cement mortars lose from 2 to 40 per cent. of their strength.

Tests in the Royal laboratory of Berlin in 1886, showed from 2 per cent. to 33 per cent. loss in different cements under different conditions when subjected to freezing.

W. W. McClay, M. Am. Soc. C. E., showed that the attempt to prevent the injurious effect of frost by heating the material and then using it in freezing temperatures was more hurtful than using the ingredients cold. In two sets of briquettes made of cement paste, one made at 45 degrees F. and the other at 100 degrees F., and treated exactly alike until broken, the strength of the heated mortar was found to be only 7 to 20 per cent. of that of the cold mixture. In case of a mortar of 1 cement and 2 of sand the strength of the heated mixture was only 30 per cent. of that of the cold mixture. This set of experiments, however, was upon one brand of cement only.

The Austrian Society of Engineers and Architects made some practical tests in the winter of 1892-93. They constructed 14 brick and stone walls, 3 feet, 4 inches long, 6 feet, 8 inches high, and 10 inches thick, using the following mortars: (1) common fat lime mortar. (2)

*Thesis of Frank Haas and John A. McGraw, on "Effect of Magnesia on the Strength of Cements when Subjected to Freezing."

Roman cement mortar. (3) Portland cement mortar. (4) One part Portland cement and two parts lime. (5) Cement and slag mortar. (6) A patent frost proof mortar.

All mortars were one part cementing material to two parts of sand. The walls were torn apart during the following summer. Their conclusions were: (1) That lime for a cementing material is entirely unsuited for cold weather construction. (2) That Roman cement can be used with fairly good results in brick masonry, but is not safe for rubble masonry construction in freezing weather. (3) That Portland cement mortar is not seriously affected in freezing weather and is especially good when used with salt. (4) That mortar mixed with warm water (77 degrees F.) showed about the same loss of strength as when cold water was used. (5) The frost proof cement and the Portland cement with salt showed very little loss of strength when frozen. (6) That dry brick and stone are necessary to safe construction under freezing conditions.

THE EFFECT OF HEAT UPON MORTAR.

M. Devol, of the Paris Testing Laboratory, made tests with briquettes of 1 cement to 3 of sand. They were allowed to harden in air from 24 hours to 30 days, and then placed in water at 177 degrees F. and kept from 2 to 7 days. Six brands of Portland cement were used. They resisted hot water at that age and gained about the strength in 7 days in hot water that they gained in cold water in 28 days. But when placed in hot water before being completely set, disintegration set in. Cements containing free lime when placed in hot water swelled, warped and cracked.

CHAPTER III.

THE USES OF CEMENT IN CONCRETE.

Cement was first extensively used to make concrete for foundations of large masonry structures. It may be well at this point to define concrete. Concrete is formed by a mixture of cement or lime mortar with any aggregate such as gravel, broken stone, cinders, or broken brick, the whole forming a solid conglomerate mass of stone. That formed with a cement mortar is sometimes called "beton." In this article, in speaking of concrete, that formed from natural or Portland cement will be understood unless otherwise stated in the immediate paragraph.

FOOTINGS AND FOUNDATIONS.

Concrete becomes of particular importance in footings and foundation work. In all properly designed structures the weight of the structure should be so distributed upon the foundation soil, that no unusual pressures can be developed. Undue pressure causes unequal settlement and therefore produces excessive and unknown strains within the various portions of the structure. With the usual rough stone masonry put in place for footing courses, it is almost impossible to obtain foundations having equal strength at all points and which transfer the weight of the structure uniformly to the soil beneath. On the other hand concrete can be placed in position by unskilled labor, with reasonable supervision, and become a homogeneous monolithic mass, capable of transferring the weight of the building very evenly to the subsoil foundation.

One important advantage which concrete has over stone masonry for foundations is in the rapidity and cheapness with which it can be placed in position. Masons must have room in which to work, and space for surplus material, mortar boards, etc. But few masons can be economically employed upon the foundations of even large structures. With concrete foundations, the excavation can be limited to the size of the foundation. The material may be stored at any convenient place, mixed there and conveyed to the foundation trench in wheelbarrows, by derrick and box, belt conveyor, inclined chutes, or by any of the many approved economical methods. After being dumped into place, as many men as the work requires may be used to properly dispose and ram the material into place.

These men may be unskilled laborers, but with a skilled foreman to direct, the work can be of the best quality.

It requires from one-eighth to one-third of the time to place a concrete foundation that it requires to construct one of stone. Within thirty-six hours after the completion of the concrete foundation, work upon the superstructure may proceed.

Those that know little about concrete may question its durability. For their benefit attention is called to the durability of concrete as illustrated in the historical portion of this paper. Portions of the Carthagenian aqueduct are intact after 2,000 years of weathering. The dome of the Pantheon still survives the ravages of 2,000 years. In 1892, while excavations were being made in London, workmen came upon a heavy mass of natural cement concrete laid over 800 years ago. Blasting was out of the question, owing to the proximity to other buildings. So workmen were employed to cut out the concrete with chisel and hammer. The concrete was so hard that it turned the best steel tools.

In 1872, J. V. Farwell erected a large store at the corner of Market and Franklin streets in Chicago, with foundations and interior walls of natural cement concrete. The building is still used for mercantile purposes with the concrete portion apparently as perfect as ever. Another of Farwell's buildings, erected in 1869, was in the path of the great Chicago fire of 1871. While the interior partitions of wood were burned out, the walls of concrete stood, so that within a very short time the building was repaired and was used by the Government for court, treasury and customs offices.

The United States Government in erecting the postoffice building in Chicago, in 1872, built it upon a cement foundation slab several feet thick extending under the entire building. In 1897 that building was torn down to make room for the new Federal building recently completed. The contractor was compelled to use steam drills and dynamite to remove the concrete, and because of its refractory nature was so delayed in finishing his work, that it entailed the payment by him of a penalty of $100 per day for several weeks. With such a record for natural and "Roman" cements, greater results may be expected from the more perfect Portland cements.

HEAVY CONSTRUCTION.

From footing courses and foundation walls to abutments, retaining walls and heavy superstructure was but a step.

These are constructed both of massive concrete blocks and in monolithic form.

WALLS.

In the construction of the Consolidated Lake Superior Power Co.'s plant at Sault Ste. Marie, Mich., immense concrete blocks with mortised

Fig. 12.—Concrete Blocks for the Power House of the Lake Superior Power Company.

Fig. 13.—View of the Pocket Walls of the Lake Superior Power Company, Showing Use of Concrete Blocks.

joints were used in building the walls of the wheel pits. Figures 12 and 13 show the blocks and the wall respectively.

It is only during the last decade that railroad companies have been developing concrete construction along these lines to any extent. The Illinois Central, the New York Central and Hudson River railroad, and other large roads are now doing a great deal of concrete work.

ABUTMENTS.

In many cases when the old abutments and masonry walls are still in fair condition, but are not heavy enough for the increased weight of bridges and rolling stock, or because of added fills, the old masonry has been re-enforced by an additional casing of concrete, thus preserving the old masonry and adding a large percentage of strength to the structure. In other places the old masonry is removed entirely and concrete substituted.

Fig. 14.—Concrete Abutment on the D., S. & U. R. R., Near Dayton, Ohio.

Some railroad companies have shown timidity in using concrete to entirely replace stone for piers and abutments of long span bridges; especially for the bridge seats, because of an uncertainty as to the durability of concrete under vibrating and impact strains. The New York Central and Hudson River railroad limits the use of concrete piers or abutments to bridges having spans less than 200 feet long.

The Dayton, Springfield and Urbana Electric Road has lately constructed two large abutments to carry their road over the tracks of the

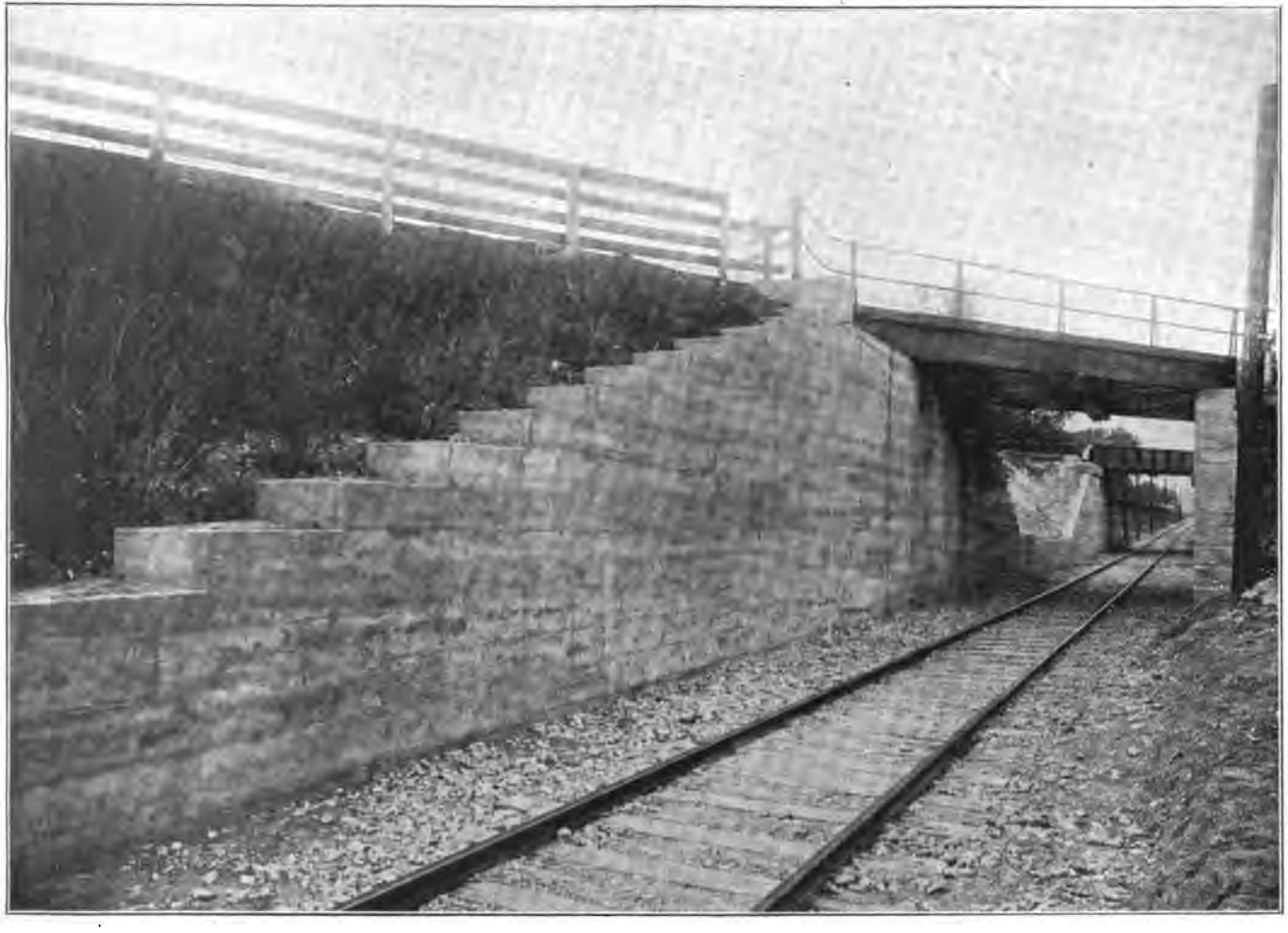


Fig. 15.—A Concrete Abutment on the T. & M. R. R., Near Toledo, Ohio.

C. S. & H. R. R. about three miles east of Dayton. These were constructed of a rich concrete of 1 cement, 2½ sand and 5 broken stone. The largest of these abutments makes an angle of about 45 degrees with the center line of track and will support about 21 feet of earth behind the wall. It is about 120 feet long and contains 590 cubic yards of concrete. The concrete cost about $5.75 per cubic yard, day labor being $1.50 per day of ten hours, and cement $2.10 per barrel. Figure 14 illustrates the abutment near Dayton, Ohio. Figure 15 shows an abutment upon the Toledo and Monroe Railway.

The Erie Railway is using concrete in nearly every place where stone was formerly used, in culverts, ashpits, foundations, etc. Furnace slag is used in place of gravel or stone. It only costs the railroad company for the hauling, as the furnace owners load it onto the cars for the sake of getting rid of it.

Concrete costs the railroad company about $3.50 per cubic yard. The sand costs them about $4.00 per car of 20 cubic yards, cement $1.40 per barrel, and the slag only the cost of hauling.

CULVERTS.

The New York Central, the Illinois Central and many other large roads are using concrete almost exclusively for arch culverts. With the old stone culvert construction the roads were at a continual expense for repairs, pointing up, repairing wing walls, etc.; but with a well built concrete arch and wing walls, the culvert is in place for all time. A smooth impervious surface is presented to the elements so that weathering has practically no effect upon the structure. Besides being cheaper for maintenance, the concrete arch saves the expensive first cost of stone cutting in skew arches. Figures 16 and 17 neatly illustrate the decay of an old stone culvert and the smooth, water resisting surface of the concrete culvert replacing it. These pictures were taken of a culvert upon the Panhandle Railroad in the western part of Columbus, Ohio. Figure 19 shows a double culvert.

RETAINING WALLS.

Concrete retaining walls are being extensively used in the track elevation and depression carried on in such gigantic scale by the railroads entering Chicago.

The Lake Shore, and the Chicago and Rock Island railroads enter the fine large Van Buren Street station in Chicago over elevated tracks upon a fill 16 feet in depth held by concrete walls on either side. The wall along the east right of way from a point 140 feet south of Polk street has a section as shown in figure 18. The trench for the foundation is excavated about four or five feet deep, the aim being to get below frost line. The foundation is then laid with natural cement concrete of 1-2-4 proportions, to within about a foot of the surface; then continued to a

Fig. 16.—A Stone Culvert Near Columbus, Ohio, Showing Deterioration by Weather.

Fig. 17.—A Concrete Culvert Replacing That Shown in Fig. 16.

finish with Portland cement concrete of the proportions 1-3-6. The excavation cost 50 cents per cubic yard, natural cement concrete $4.00 per cubic yard and Portland cement concrete $6.25 per cubic yard, making the cost of the maximum section as shown in the accompanying figure to be $23.65 per lineal foot of wall.

The wall upon the west side of the right of way is designed with a base width of four-tenths its height, consequently is considerably cheaper; the cost of such a wall being $20.53 against the cost of the first or a saving of 15 per cent. on the basis of the lighter wall, the latter being perfectly safe practice.

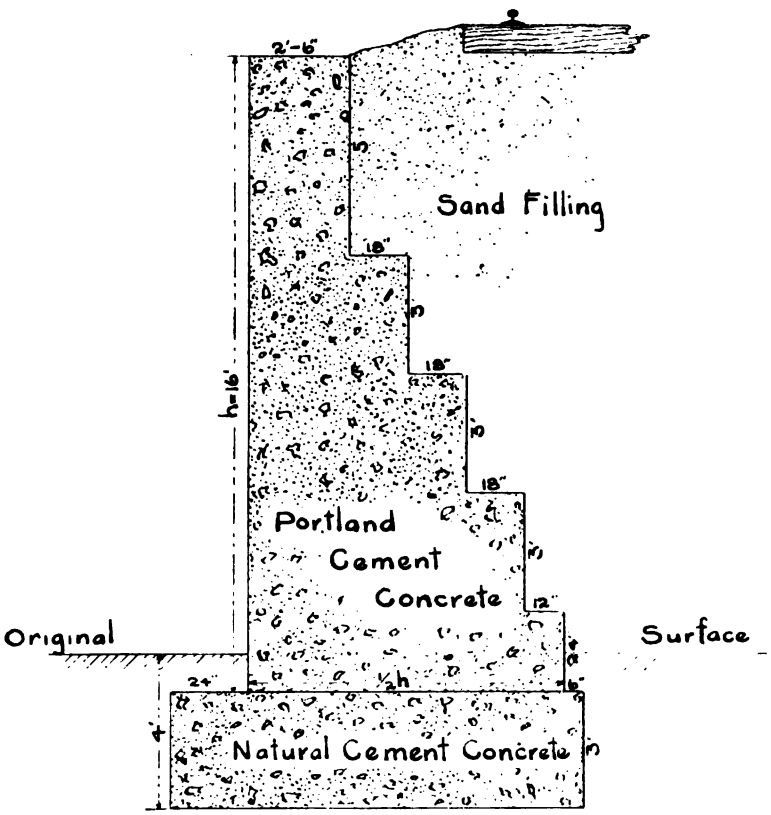


Fig. 18.—Section of Retaining Wall C. R. I. and P. R. R. Showing Maximum Section.

The contract specifies that the cement shall be of first class quality, acceptable to the railway company. The sand shall be what is known as torpedo sand. The stone shall be good crushed limestone. The wall was

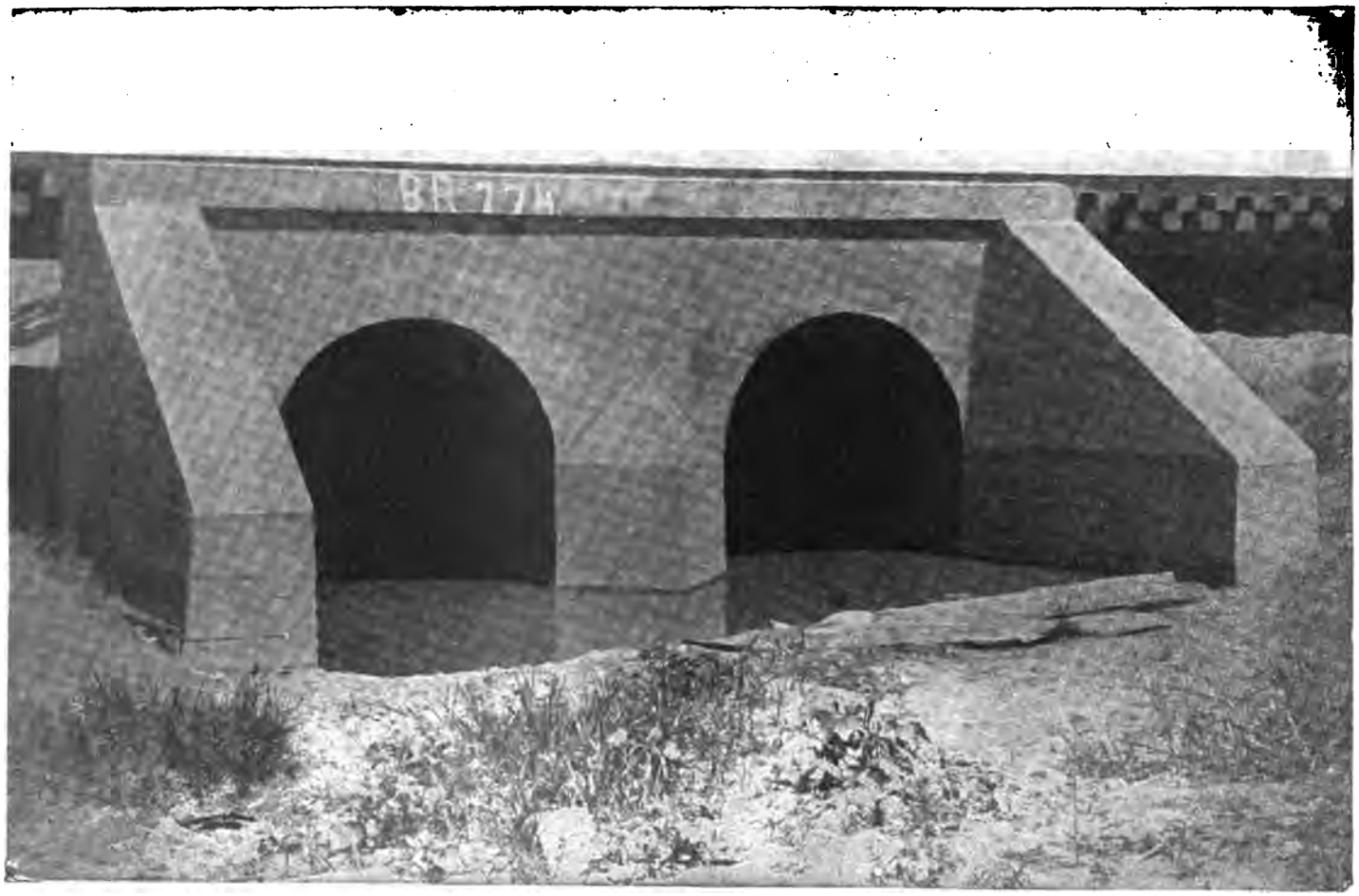


Fig. 19—Double Six-Foot Culverts, Rankin, Ill.

put up in 48 foot sections, thus leaving a vertical joint every 48 feet for expansion. In the wall on the eastern right of way, the forms were held together by iron rods running through gas pipes; these rods were afterwards removed and the holes cemented up. On the western right of way the forms were held together by wires which were cut off after the forms were removed. This method of placing forms is illustrated in Figure 20.

LEVEE WALLS.

Similar to the retaining walls are the walls built to withstand the pressure of high water along river banks. While levee walls are usually

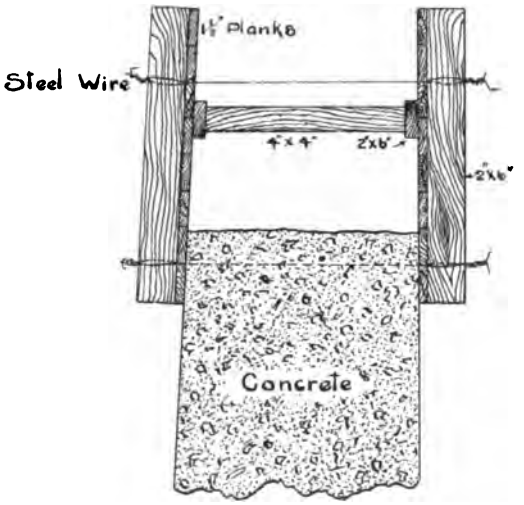
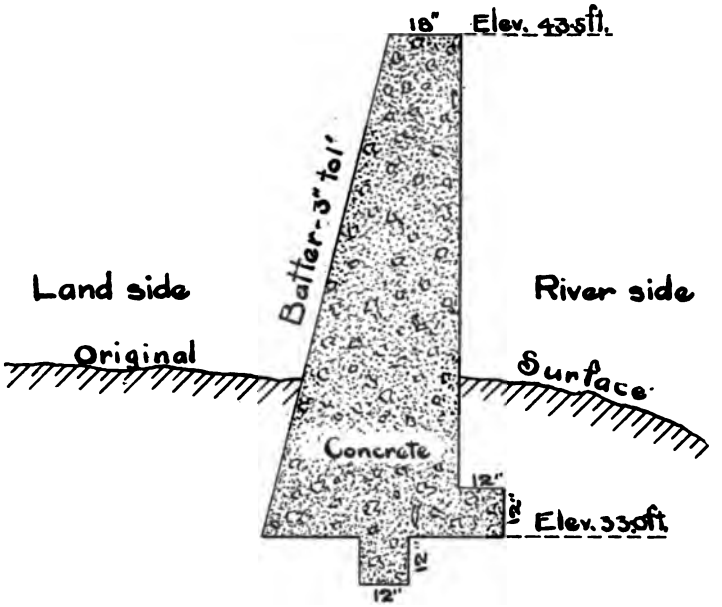


Fig. 20.—Section of Concrete Wall-Form, Showing Method of Holding and Bracing Forms, C. R. I. and P. R. R.

built of earth, the city of Columbus has 245 feet or more constructed of concrete. Property and space in the heart of cities often becomes too valuable to use ordinary methods of construction in making the necessary improvements, and recourse is had to what at other times would be more expensive methods. In this case space was too valuable for earth embankment and a concrete wall was constructed by the city with day labor. Figure 21 shows a section of this work.

The wall was 18 inches thick at the top and 50 inches at the bottom with a maximum height of 11½ feet. The heart of the wall was constructed of concrete with the following proportions, 1 part Portland cement, 2½ parts sand and 5 parts crushed gravel. The face of the wall

for a thickness of two inches was of mortar, 1 cement to 2 sand. A careful force and expense account was kept of the work which was done in



Section of Concrete Levee Columbus, Ohio.

Fig. 21.

two pieces, one of 185 feet and the other 60 feet in length. The cost of each is as follows:

TABLE NO. 18.

Cost of Levee wall at Columbus, O.

Items used in each cubic yard of Concrete.	Cost per cubic yard upon	
	60 ft. length.	185 ft. length.
0.94 barrel Portland cement at $2.15	$2.021	$2.021
1.10 cubic yards of crushed gravel at $0.75	0 825	0.825
0.55 cubic yard of sand at $1.25	0.687	0.687
Labor mixing—placing and ramming at $0.15	1.160	1.324
Extra cost per yard, facing with 1 to 3 mortar	0.264	0.221
Cost of labor, erecting forms	0.265	0.232
Cost of materials in forms	0.379	0.391
Deterioration of tools and equipment	0 042	0.055
Total cost per cubic yard	$5.643	$5.756

FORTIFICATIONS.

Concrete is extensively used by the U. S. Government in the construction of gun foundations and emplacements in magazine vaults, bomb

proofs, and in all masonry construction about the sea coast defences. The great disappearing guns are set in immense concrete masonry chambers with concrete foundations for the machinery.

MONOLITHIC CONCRETE HOUSES.

The oldest concrete house built in the United States is of monolithic concrete. It was built on Staten Island, N. Y., in 1837, of natural cement concrete. Although badly weather worn and dilapidated, this house still stands and was inhabited by one or two families when the writer visited it in 1902. It must be remembered that this house was built of the imperfect natural cement made in those early years and the aggregate used was not carefully selected, but portions were composed of brickbats, irregular and rather large sized broken stone, etc., therefore the dilapilation shown. In front of the house at the gateway, lie two cast concrete lions, one badly cracked and crumbling, the other yet in fair condition after many decades of weathering. Figure 22 shows a front view of the house with the figure of one of the lions.

Fig. 22.—The Oldest Concrete House in the United States. Built on Staten Island in 1837.

CONCRETE BLOCK HOUSES.

Of the later forms of concrete house construction, none is neater, simpler, nor more economical than that constructed of the various forms

of blocks now manufactured of which the Palmer hollow block is a good illustration. The simplicity with which these blocks are molded and the latitude of design obtained upon the one simple machine leaves little more to be desired. The machine covers but small space, is fairly light, is readily moved from place to place and is easily prepared for molding different shaped or sized blocks. Four men, two mixers and two tampers, will make from 100 to 125 blocks a day. The usual size for the blocks are 32 inches by 9 inches by 10 inches. The sides and ends of the machine swing out and down upon hinges. The hollow places in each stone are formed by metal wedges or cones raised into place, through the base plate by means of a cog and ratchet attachment. The side plates can be readily changed so as to substitute smooth, quarry faced, or ornamental facing for the stone as desired.

Fig. 23.—Palmer Concrete Hollow Block Machine.

The concrete is tamped into the machine, upon thin iron base plates, so that as soon as the block, which is made of rather dry concrete, is finished, the sides are let down, the hollow centers lowered and the block is lifted out on this base plate and allowed to remain upon it until firmly

set. Narrow iron tampers are used to tamp the concrete into the mold. The top of the block is troweled smooth before removing it from the form. After three or four hours, or as soon as the concrete has sufficiently set, the blocks are wet down, water being applied twice a day for three or four days. The blocks are allowed to set ten days or more before being laid in the wall.

Four men can lay about 60 blocks a day, equal to about 2,200 to 2,500 bricks, or 112½ square feet of wall surface.

The concrete is made of 1 part Portland cement and 5 parts coarse sand. Tests made upon such blocks at four months of age have shown 80,000 pounds compressive strength. Figure 23 shows the Palmer machine which is about two feet wide, three feet long and three and one-half feet high. Figure 24 shows the various shaped blocks and the purpose for which each is made. Figure 25 shows a residence under construction near Indianapolis, Ind. Figure 26 is from a picture of a residence in Springfield, Illinois.

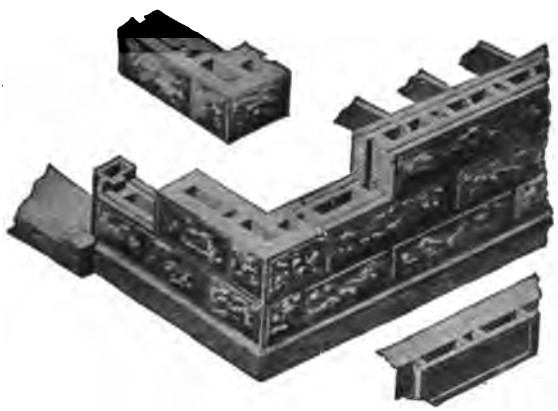


Fig. 24.—Palmer Concrete Hollow Blocks.

Mr. Palmer claims that each standard block takes the place of forty bricks; that each block can be made for twenty-two cents and hence economically replaces brick at $5.50 per one thousand. And further, that these blocks can be laid much more rapidly than brick, saving something also in labor.

An Estimate of the Cost of Making the Palmer Block.—Assume cement to cost $2.00 per barrel, sand, $1.60 per cubic yard, common labor, $1.50 per day, with the foreman's wages $2.25 per day, the estimate to be based upon the work of one machine using four men. The regular block contains 1⅛ cubic feet of material and weighs about 165 to 170 pounds. Assuming the weight of cement at 80 pounds and that of sand at 100 pounds and assuming that four men can make 100 blocks per day of eight

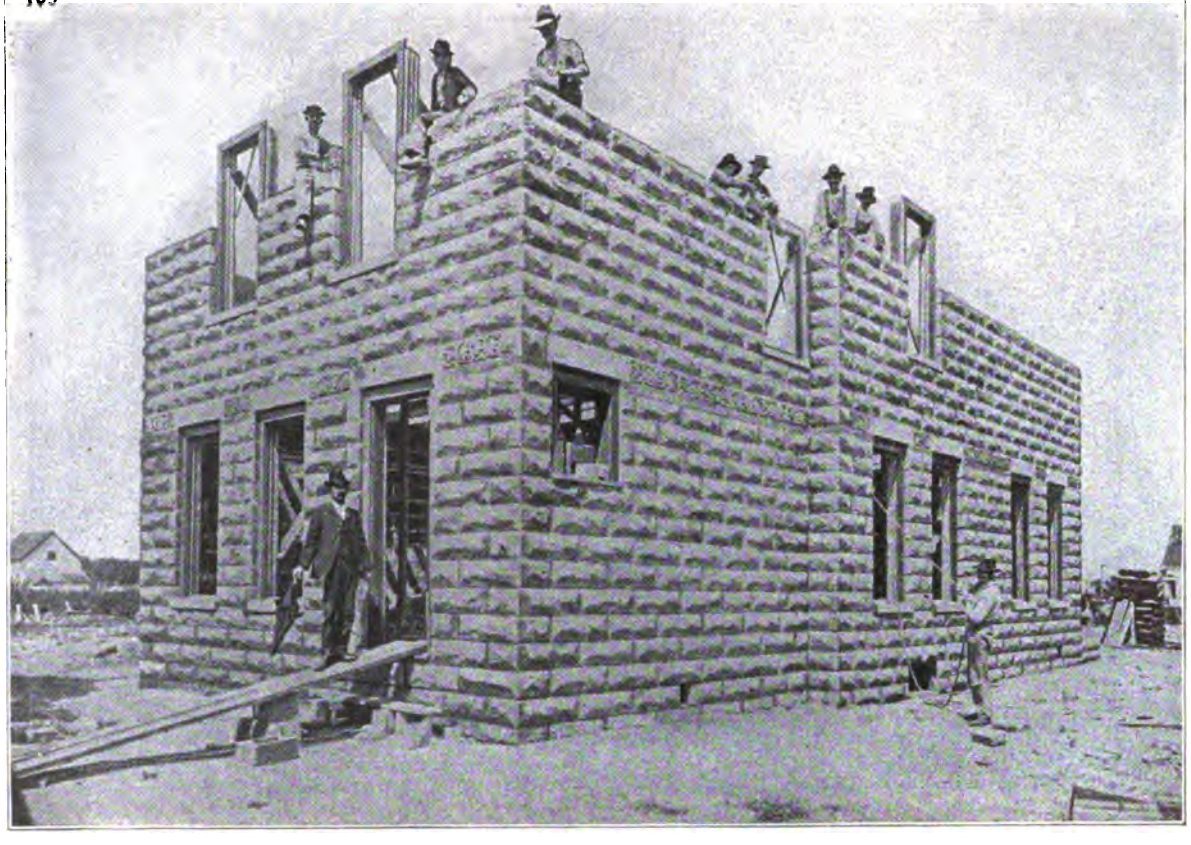


Fig. 25.—A Residence in Indianapolis Being Constructed of Concrete Blocks.

hours, the following will be an approximate estimate of the cost of one hundred blocks:

Four men, 3 at $1.50 and 1 at $2.25	$6.75
Cement, 5.8 bbl. at $2.00	11.60
Sand, 5.8 cu.yds at $1.60	8.00
Cost of one machine plan, $750, int. at 6%	0.15
Depreciation, 20%	0.05
	$27.00

or 27 cents per block equal to brick at $6.75 per 1,000. Using the table in Prof. I. O. Baker's book on Masonry Construction, page 86, the cost would be 23½ cents per block equal to brick at $5.70 per 1,000.

Mr. F. E. Kidder,* author of "Architects' and Builders' Pocket-Book," made a test of the cost of concrete blocks with a machine of the American Hydraulic Stone Company's make during March, 1903. The test was made on facing block for a 10 inch wall; two of these blocks would lay 9 inches by 24 inches in the wall. The main portion of the block was composed of 1 part cement to 6 parts sand and gravel, with a face of 1 cement to 2 sand.

Cost Per Square Yard of Wall.

Labor 1 man, 1 hour 15 min., at $2.00 per day of 10 hrs...	$ .25
Cement, 0.78 sack at $0.62½ per sack	.48¾
4 cu. ft. of sand and gravel at 75c. pepr 1¼ cu. yds	.09
Extra cost or facing material	.01¼
Cost of twelve blocks	$ .84
Cost of mortar and laying 1 sq. yd	.48
Cost of hauling blocks to place of conctruction per yd	.10
Total cost of 1 sq. yd. of 10-inch wall	$1.42

He estimated brick layed at $12.50 per 1,000, and adding $30.00 per 1,000 for pressed brick facing, making no allowance for cut stone trimmings, the cost for a 9-inch brick wall would be $3.57 per square yard, and for a 13-inch wall, $4.41 per square yard.

BRIDGES.

In bridge building as in other lines of construction concrete has taken its place as a permanent structural material. In small country highway bridges, the highway commissioner frequently considers himself not only able to decide upon the character of bridge to be erected, but also competent to design it. Wooden or metal bridges are erected and from the day they are finished not a thought is given to their maintenance. They are allowed to weather, rot and rust away until some accident occurs or

Eng. News, Sept. 17, 1903.

Fig. 26.—Residence Built of Concrete Blocks, Springfield, Ill.

warning of such accident forces the attention of the authorities to the condition of the structure. Neither is the commissioner altogether to blame—for when one official more careful than others reports the necessity for the proper painting and maintenance of bridges, he will probably meet the serious objection from the tax payer—that "there are enough expenses now, without trying to make an out-of-the-way bridge look pretty." If anyone doubts the expensiveness of this careless method of bridge maintenance, he has only to examine some of the highway bridges crossing the Olentangy and Scioto rivers in Franklin county, Ohio, to note how little of real value is left in bridges after a few years of neglect.

Concrete bridges and culverts, however, have no corrosion. If they are properly constructed they neither weather nor rot. The commissioner may be as careless as he chooses, the tax payer need not be taxed again for that particular bridge, it is there for the tax payer's lifetime, and probably that of his son's also.

Concrete bridges are constructed both of plain concrete and of steel concrete, mainly of the latter material. At this place only the plain concrete bridge will be considered, leaving the descriptions of steel concrete bridges to be given with other structures under that division of the subject.

Probably the first all-concrete bridge of any size constructed in this country was built at Belleville, Illinois, in 1895. It was built over Richland creek where it crosses Main street, the main traveled road leading directly to St. Louis, Mo. It has a span of 40 feet with a rise of 7 feet and is 52 feet wide over all. The abutments, spandrels, and haunches were constructed of Louisville cement concrete in the proportions of 1 cement, 3 sand and 5 crushed stone. The arch was built of Dyckerhoff Portland cement concrete of the same proportions. Exposed finished surfaces were of mortar composed of 1 cement to 2½ parts of crushed granite. The arch is 24 inches thick at the crown and 30 inches thick at the haunches. It cost $10,500; the bids upon a brick structure in this place ranged from $11,259 to $12,830.

After eight years' service, the city engineer of Belleville, Mr. Louis Graner, writes: "The bridge is in perfect condition and the city has had no expenditure in any way since its construction. It shows no cracks and the weather has had no effect on it."

There are a great many concrete bridges throughout the United States, but the majority of them are of steel concrete construction and some of them will be described under that head.

TOWER SUBSTRUCTURES.

Massive concrete is also used in foundations, pedestals and substructures of towers, and monuments. The statue of Liberty on Bedloe's Island is placed upon a massive stone faced concrete pedestal rising for

90 or 100 feet above the top of an all concrete base which is itself 50 or 60 feet in height above the surface of the island. The interior surface of all the concrete is as good as the day it was built. In places where it has been cut into, the material appears more refractory than ordinary building stones. The surface of the base was plastered with cement mortar after the construction forms were removed and this mortar surface shows an immense number of hair-cracks which give the base an unseemingly appearance, but which do not injure the strength of the foundation. These cracks do not appear on surfaces not exposed to rapid drying. The base is built of a natural cement concrete having the following proportions, 2 parts Rosendale cement, 2 parts sand, 3 parts small broken stone and 4 parts of 2 inch stone. Above ground the proportions are 1 Portland cement, 1 Rosendale cement, 5 sand and 6 stone. The total height of the statue above water level is 324 feet. Figure 27 shows the lower base of the statue of Liberty. Close examination will disclose the hair-cracks so common to plastered surfaces. Figure 28 shows the Statue of Liberty.

Fig. 27.—Concrete Foundation Statue of Liberty, New York Harbor.

The Washington monument is also an instance of the use of concrete for heavy foundations. The monument is of marble and granite 555 feet high and 50 feet square at the base. The corner stone was laid on July 4, 1848. The construction was carried on in a desultory manner so that the monument was not completed until 1884. In 1877, when the tower was about 175 feet high, it was decided that the original foundations were not of sufficient extent and strength to safely support the finished tower. An additional concrete sub-foundation 13½ feet deep and covering 21,000 square feet of surface was skillfully constructed beneath the original foundation in sector shaped pieces. The concrete was composed of 1 cement, 2 sand, 3 gravel and 4 broken stone. The result seems to be perfectly satisfactory.

Fig. 28.—Statue of Liberty, New York Harbor, Showing Concrete Pedestal in Full.

SEA WALLS.

The concrete sea wall built by the United States government during its occupation of Cuba, along the sea front of the fort of La Punta in Havana, illustrates the use of concrete for this purpose. A wall was first planned for this place by a Spanish officer in 1875, but was not built. When

the Americans occupied Havana, this shore was used for a refuse dump and was in a seriously unsanitary condition. Under the changed conditions, it was necessary to construct a different improvement than that planned by the Spanish officer. The work was done under the direction of Major Wm. M. Black, of the Engineering Corps of the U. S. A. The wall was set back 30 feet from ordinary high water mark and a paved toe extends down the slope about 26 feet, having stones set in the paving and extending above the surface of the same in order to retard the wave effect. Three hundred and sixty-seven feet of wall was built during the last four months of 1900. The toe was built first to act as a protection during the erection of the wall proper, which was afterwards built in sections from 33 to 50 feet long with vertical dovetail joints, to bond the sections together. Near the fort, a broad flight of steps was constructed to give access to the beach and to break the effect in appearance between the modern concrete wall and the ancient masonry of the fort. The total cost of the improvement was $9,567.00. The wall was constructed of a 1-2½-5 concrete, faced 2 inches deep with a 1 to 2 mortar. The facing was placed in the molds and rammed at the same time with the body of the concrete.

The toe pavement was constructed of a 1-3-6 concrete top-dressed with 2 inches of 1 to 2 mortar with large stones projecting above the surface as shown in the illustration, figure 29.

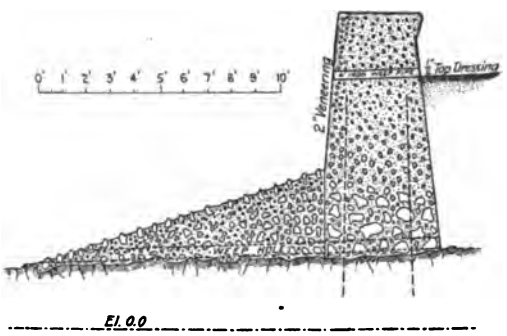


Fig. 29.—Section Showing Sea-Wall Building at Havana, Cuba.

Galveston Sea Wall.*—In September, 1900, a storm of great severity swept over the island upon which the city of Galveston, Texas, is situated, carrying the waters of the gulf over the island to a depth varying from 10 to 16 feet. The city suffered a great loss of life and property by this storm. Soon afterward a commission of engineers was appointed by the city to devise adequate means of protection against repetitions of such storms. This commission found that in 38 years 82 hurricanes originated in the West Indies of which 38 came into the gulf and 11 reached the

*Eng. News, April 24, 1902 also, Eng. News, January 15, 1903.

Texas coast, or one storm for each three and one-half years. If Galveston was to prosper, ample protection must be afforded against these oft recurring dangerous storms.

The commission proposed and the city is now building a great sea wall three and one-half miles long of solid concrete, the monolithic character of concrete suggesting a safer wall than block masonry, besides being very much cheaper in first cost.

This wall is being built upon a pile foundation, the heads of the piles extending about 2 feet above mean low water. The wall is 16 feet wide at the base, 16 feet high, and 5 feet wide at the top, with a curved water face. The base of the wall is one foot above mean low tide, resting on and enclosing the top of the piles. Extending the toe of the wall there will be 27 feet of stone rip-rap 3 feet deep, protecting the wall from under wash by wave action. Behind the wall the land will be filled to the height of the wall for a width of 95 feet; the 35 feet next the wall being paved for road and walk purposes, the remainder being well sodded.

It is estimated that the complete wall will contain 127,000 cubic yards of concrete and that the entire protection will cost $3,500,000.

Figure 30 gives a section of the wall and improvement as it is being built.

Lincoln Park Shore Wall.—The concrete shore wall along the lake in Lincoln Park, Chicago, is another example of first class concrete work. Like the Havana wall, the Lincoln Park wall is protected from the direct assault of the waves by an intermediate pavement, which in this case is of granite blocks firmly set between a strong curbing at the water's edge and the wall. On the inner or land face of the wall is a concrete gutter or bicycle path. The illustration in figure 31 shows the general appearance of the improvement which has been in for ten or fifteen years.

At Jackson Park, Chicago, similar improvements with a broad concrete walk were constructed previous to the World's Fair.

BREAKWATERS.

Concrete breakwaters have been constructed for many years, and by nearly every country having a sea coast. Concrete superstructures upon random stone substructures have been built in India, Turkey, Russia, Austria, Holland, England, and the United States. They range from 24 to 50 feet high and from 12 to 38 feet wide on top.

At Newhaven, on the south coast of England, a plastic concrete breakwater 1,500 feet long and 30 feet wide, 10 feet above high water, was constructed in 1880-85. It was 50 feet wide at the bottom some 15 feet below low water, at spring tide. The foundation up to 2 feet above low water was laid in large jute bags containing 100 tons of concrete. They were dropped into place from the bottom of a patent steam hopper barge. When in

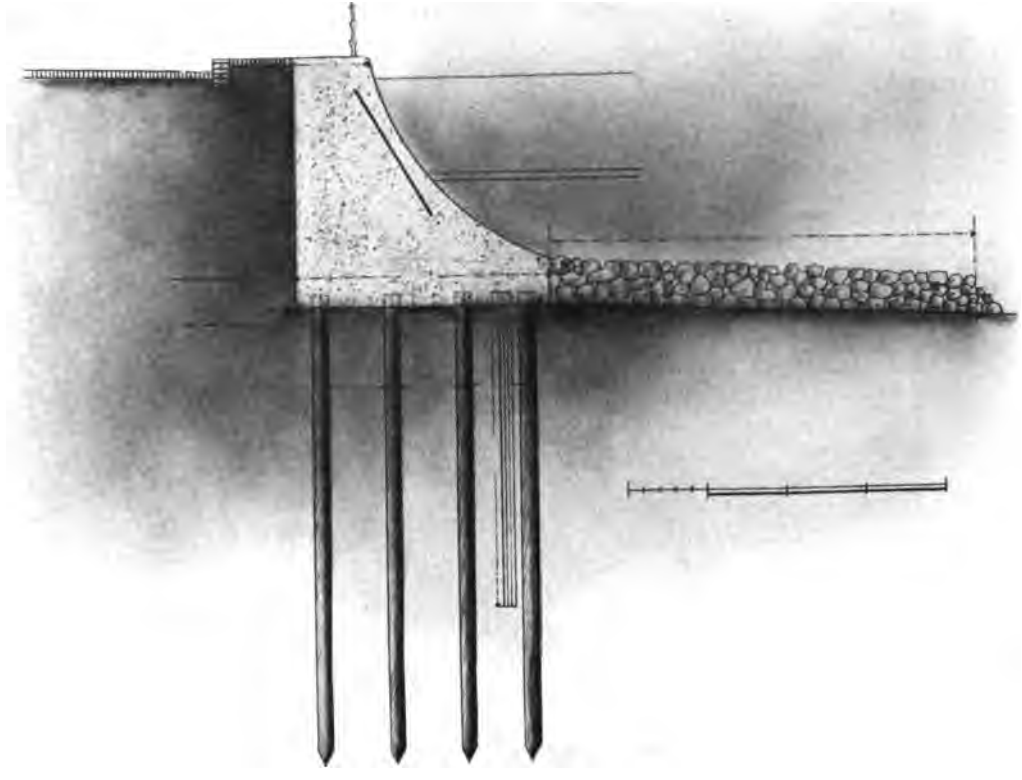


Fig. 30.—Sea-Wall in Process of Construction at Galveston, Texas.

place and flattened out the bags were about 2½ feet thick. The forms for the superstructure were of timber trussed with 1¼ inch iron rods, the sheeting being of 3 inch plank, with planed edges and surface. The concrete was composed of 1 cement to 7 sand and gravel, except in quiet water and unexposed places where 9 parts of sand and gravel were used. The average cost of the concrete in place was $5.50 per cubic yard. This work has withstood the wave action excellently and is not affected by salt water.

Fig. 31.—Concrete Shore-Wall, Lincoln Park, Chicago, Ill.

The timber breakwater constructed at Marquette, Mich., in 1870, became inadequate for the needs about 1888 and efforts were made to have the government extend it. These efforts finally succeeded in 1895, and the government proceeded to improve the harbor. The old breakwater was in bad condition above low water and it was decided to replace the timber top with a permanent one of concrete.

The original structure was cut down to one foot below low water and the concrete superstructure with dimensions as shown in figure 32 was added. Within this solid concrete mass on the harbor side a gallery 2.83 feet wide and 6.25 feet high was built to give a passageway during heavy storms to the lighthouse at the end of the breakwater. The superstructure was made in 10 foot sections, alternate sections being constructed and allowed to set, then the intermediate blocks built between. The proportions of Portland concrete used in the base beneath water level was 1 part cement, 2½ parts sand, and 5 parts stone, and cost $6.35 per cubic

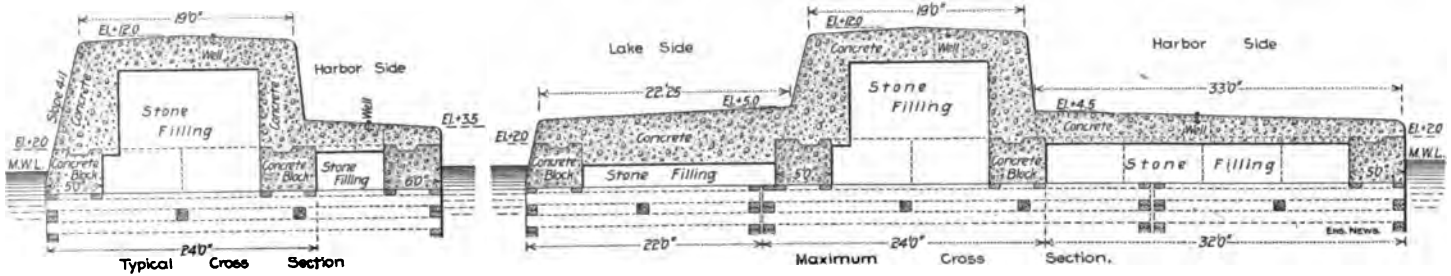


Fig. 33.—Section of Breakwater, Buffalo, N. Y.

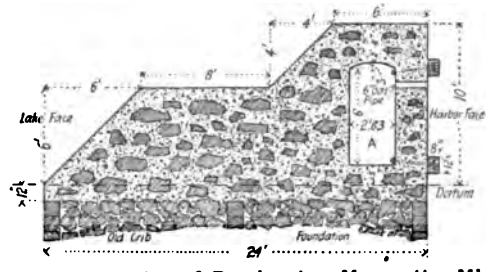


Fig. 32.—Cross Section of Breakwater, Marquette, Michigan, Showing Passageway to the Lighthouse at the End.

yard in place. Milwaukee natural cement concrete was used for about 27 per cent. of the heart of the mass above low-water; this cost $3.64 per cubic yard, and reduced the cost of the total mass of concrete to $4.72 per cubic yard, in place.

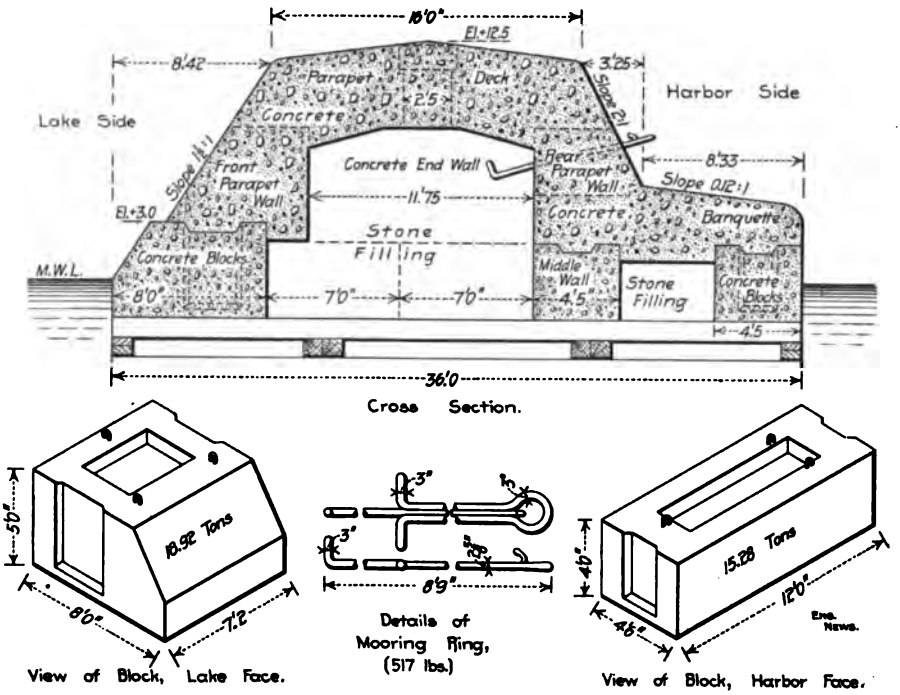


Fig. 34—Section of Buffalo Breakwater Showing Method of Construction.

The section shown will illustrate the manner of construction and the method of reducing the shock of wave action.

The Buffalo breakwaters, but lately completed, constitute one of the largest pieces of such work undertaken by the Government. The Buffalo breakwaters are known as the Stony Point, South Harbor, Old and North breakwaters, comprising 19,872 feet, or 3¾ miles of harbor protection, enclosing about 1,000 acres of harbor. Some portions are rock-filled timber cribbing, other portions are loose rock rubble work, but large portions are now capped with concrete either in large blocks or monolithic. In portions of the work, concrete blocks 7.2 by 5 by 8 feet in dimensions and weighing 18.92 tons were carefully set in place and interlocked by dovetail or joggle joints. On top of these, monolithic concrete caps were constructed. Sections are given in figures 33 and 34 showing the different forms and methods of construction used. Figures 35 and 36 show the work in different stages of construction.

Fig. 35.—View of Buffalo Breakwater in Process of Construction.

Fig. 36.—Another View of the Buffalo Breakwater in Process of Construction.

UNIVERSITY

The following table gives the cost for various portions of this work:

TABLE No. 19.

Cost of Breakwaters.

	Superstructure per lineal foot.	Concrete blocks per cubic yard.	Mass concrete per cubic yard.
Old U. S. Breakwater, solid concrete superstructure, 1889	$110.19	.....	$9.19
Old U. S. Breakwater, solid concrete superstructure, 1891	108.32	.....	8.21
Old U. S. Breakwater, concrete shell.....	72.26	$ 6.64	6.64
North Breakwater, 36 foot section.....	56.34	7.10	5.65
North Breakwater, 24 foot section.....	46.02	7.10	5.65
South Harbor, concrete shell superstructure.....	108.49	10.00	9.40

Concrete wharves, piers and river jetties have also been constructed. The Eads' jetties at the mouth of the Mississippi River are for a portion of their length of concrete, an illustration being given in figure 37.

SEWERS.

During the last few years concrete has been used in increasing quantities for sewer construction. The first use of concrete for that purpose, in this country, appears to have been in 1891. The Waring Sewer Pipe Co., of Providence, R. I., patented during that year a method of manufacturing sewer pipe in sectional pieces. They cast it in smooth iron molds, the invert and arch, separately. The invert pieces were rabbeted or grooved at the ends so that when two pieces were laid end to end the groove could be filled with mortar.

The arch pieces had beveled shoulders which fitted snugly upon the top edges of the invert; the arch joint being plastered over with mortar from the outside. Lateral connections were made through specially molded junctions. The 4-foot main sewer, in Middlesborough, Ky., was constructed by this company, the invert being built in place. The cost, according to the construction company, was 25 per cent cheaper than brick sewers.

In the same year A. C. Chenowith, C. E., invented a seamless concrete duct which was applicable either to sewer or electric duct service. The first piece constructed was for electric ducts in Yonkers, N. Y. A thin iron ribbon was wound spirally over a collapsable wooden mandrel or core, a bed of plastic concrete was laid in the trench and the core laid upon this and then covered with another layer of concrete. The wedges were then taken out and the mandrel removed leaving the iron ribbon as a shell to support the concrete until set, when the ribbon could be readily removed.

Fig. 37.—The Use of Concrete at the Jetties, Mouth of Mississippi River.

In 1894 over a mile of ten-inch and twenty-four inch pipe of this make was laid at Scarborough-on-Hudson, of a concrete composed of 1 cement, 2 sand, 5 stone at a cost of 30 cents per foot for the 10 inch and 95 cents per foot for the 24 inch sewer.

Edward Mahun, C. E., constructed a large egg-shaped sewer, 2 feet by 3 feet and 2 feet 10 inches by 4 feet 3 inches in dimensions, of monolithic concrete, for the city of Victoria, B. C., in 1891. This shows that several engineers began the work at about the same time.

A large concrete storm sewer was constructed for Maelbeek creek, Brussels, Belgium, in 1895. This sewer had a circular form with a diameter of about 15 feet in one part, and a section in another part of 29 feet 7 inches wide by 9 feet high. The remarkable feature of this large concrete structure was the leanness of the concrete. The foundation was of 1 part cement, 6 parts sand and 12 parts gravel, while the sides and arch were of 1 part cement, 4 parts sand and 8 parts gravel with a 1 inch face of 1 to 1 mortar.

Reading, Pa.—In 1896 the city of Reading, Pa., constructed a large amount of concrete sewers ranging in size from an oval sewer 4 feet 8 inches wide by 7 feet high to a circular sewer 14 feet in diameter. Some $250,000 to $300,000 was expended in combined sewers for the city. These were plain concrete sewers—no metal being used to reinforce the concrete. The concrete was proportioned as follows: 1 part cement, 3 parts sand and 6 parts broken stone or gravel. The work was plastered upon the inside with cement mortar after the forms were removed. This plaster coat has peeled off in a very few places of limited extent, otherwise the appearance of the sewer is as good as when it came from the forms.

The writer visited Reading in the summer of 1902 and examined the sewers, but could see no appreciable evidence of wear or disintegration except as already stated. The engineer said there were velocities ranging up to 19 feet per second or greater, in some places in these sewers. At the outlet an abrupt 90 degree bend in the sewer shows no evidence of wear.

At the time the contract was let there were 15 bidders upon the work. Alternate plans were drawn, one for brick, the other for concrete —the 14 foot sewer with 4 rings of brick or 18 inches concrete, the 10 foot sewer with 4 rings of brick or 15 inches of concrete, the 6 foot sewer with 3 rings of brick or 10 inches of concrete. The average of the bids upon the concrete was 85 per cent. of the bids for building the same sewers with brick. Comparing each bidder's prices upon concrete with his prices upon brick sewers, the bids upon concrete ranged from 67 per cent. to 103.6 per cent. of the prices bid for brick sewers.

Columbus Sewers.—A brief description of the concrete sewer work now under construction in Columbus, Ohio, should also be given.

Bids were accepted April 14, 1903, upon three different plans of sewer construction for the Central Relief and the Beck Street sewers. These sewers range from 51 inches to 10 feet 6 inches in diameter.

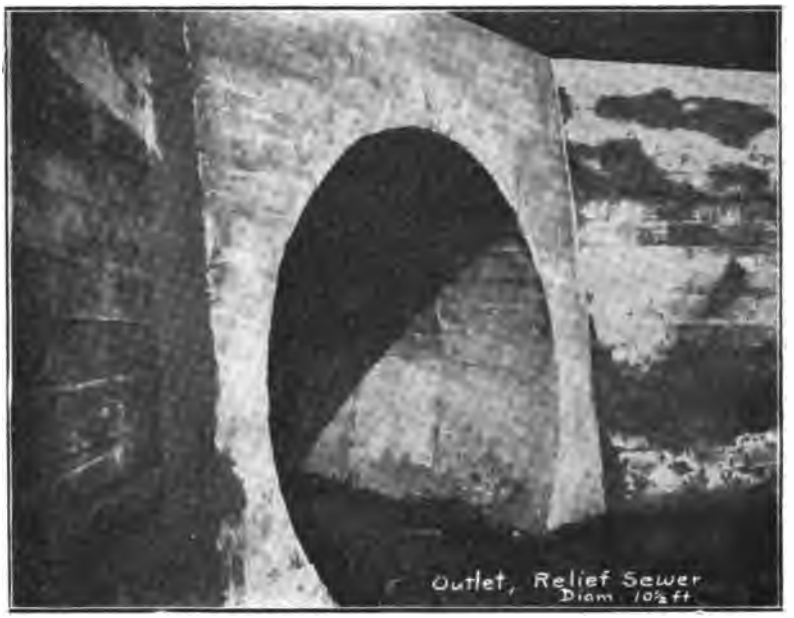


Fig. 38.—Outlet of the Relief Sewer, Columbus, Ohio.

One design was for the customary brick sewer, another for reinforced concrete and a third for plain concrete. But two contractors bid—number one accustomed to construct concrete sewers, number two unaccustomed to such construction. The bidder to whom concrete construction was strange bid much higher upon concrete than upon brick.

Number one's bid upon concrete was 86.6 per cent. of his bid for brick work, and only 85 per cent. of his competitor's bid upon brick work; while the bid of number two for concrete was 116 per cent. of his own bid upon brick work.

The lowest bid was accepted and the work is in progress. Figure 38 illustrates the outlet end of the 10½ foot sewer where it empties into the Scioto River.

ELECTRIC DUCTS.

Electric wires for light, telephone, telegraph and power are laid under ground in many of the large cities in tile or terra cotta pipes. In order to protect the wires and insulation from dampness, these pipes are imbedded in concrete as illustrated in Figure 39.

WATER PIPE.

In California, for a great many years, concrete pipe for irrigation and water supply purposes has been manufactured. As early as 1880, 18 inch to 24 inch pipes, 30 inches long were being made at Pomona, California, for the Pomona Land and Water Company, to bring the water supply from wells and tunnels onto their lands.

The Edison Electric Co., Redlands, California, have lately completed a gravity water power line 25,000 feet long, to their Mill Creek Power plant. It was constructed of 30 inch concrete pipe in 24 inch lengths; the shell of the pipe being 2¾ inches thick. The economy of this pipe over cast iron was largely due to the cost of freighting material to the line of work. The cement was hauled twenty miles direct from the works. Iron pipe would have been very expensive due to the great cost of hauling. Gravel was obtained right upon the work. The pipe was cast in metal forms, the concrete composed of 1 part Portland cement and 3 parts gravel, using ¾ gallon of water to a cubic foot of the mass. The pipe cost $1.00 per foot to make and $1.00 per foot to lay it. The pipes after being made were sprinkled frequently for about two weeks and then allowed to season several months before laying.

The water supply of Cuneo, Italy, is brought 5,900 feet through a concrete pipe 9⅞ inches in diameter, under a head of 78 feet. The engineer originally estimated that the pipe would have to be 7½ inches thick to withstand the pressure, but after careful tests decided to reduce the thickness to 3.15 inches. The pipe was built in 1888 or 1889 and is serving the purpose satisfactorily.

IRRIGATION DITCHES.

In 1891, an irrigation ditch at San Gabriel, California, 4 feet wide at the bottom, 6 feet wide at the top and 3 feet, 4 inches deep, was built with concrete sides and bottom. The concrete 2½ inches thick, composed of 1 part cement to 8 or 10 parts sand and gravel, was laid directly upon the clean cut excavated bottom and sides of the ditch. The sand and gravel was used just as it came from the ditch excavation. After laying, the concrete was coated by brushing in upon the surface a neat cement cream. Two years afterwards it was reported to be in good condition.

About the same time the Gage Canal, near Riverside, California, was lined with 1½ inches of cement-mortar composed of 1 part Portland cement and 4 parts sand. This irrigation canal is 22 miles long and belongs to the Riverside irrigation system. The work cost about $1.03 per lineal foot of canal. It was reported to be in perfect condition after two years' service.

These cement lined irrigation ditches have much to commend them to the farmer and fruit raiser. They are in the first place economical,

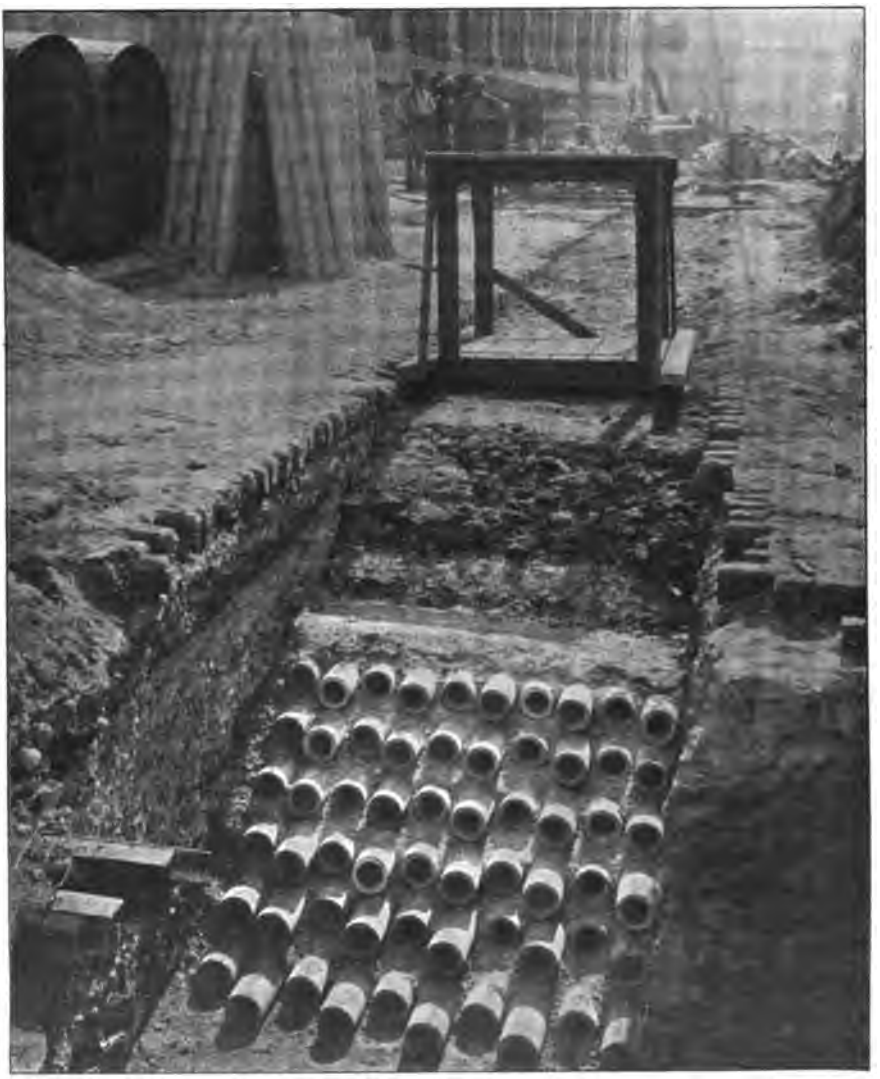


Fig. 39.—Electric Conduits Imbedded in Concrete, Cincinnati, Ohio.

saving an immense quantity of water from loss by percolation and from being taken up by useless vegetation along the line of the ditch. They prevent burrowing animals from destroying the ditch banks. They allow much flatter grades in the ditches, thus permitting larger territories to be brought within the irrigation sphere. As the surrounding ditch banks are not saturated, weeds do not grow along the canals to any great extent, therefore the farmer is not so seriously troubled with weed seeds being distributed over his farm in such immense quantities as formerly by the old open earth ditches. Within his farm limits the ditch presents a more pleasing appearance than the old weed bound ditch. It saves annually upon the cost of cleaning and repairing, which was originally required. Thus cement is a great boon to the western irrigator.

RESERVOIRS.

Mr. John Randall, of San Francisco, Cal., said he had coated a reservoir (in 1889) with a 1½ inch coat of cement mortar upon the original sand and gravel surface. The mortar used was a 1 to 5 Portland cement mortar put on in one layer while the sand surface was moist. This structure had held water for four years against a head of 16 feet. without leaking.

In the water supply system for Aurora, Ill., there is a reservoir 150 by 140 feet in area, and 12 feet deep excavated through a layer of gravel and into a stratum of shattered limestone. This reservoir is lined with concrete 8 inches thick, except above the rock where the lining becomes a wall, reinforced at frequent intervals by heavy concrete buttresses about 5½ feet thick at the base just above the rock. The concrete used was 1 part cement, 2 parts sand and 3 parts stone in the lining, and 1 part cement, 3 parts sand, 6 parts stone in the heavier masonry. This reservoir is illustrated in figure 40.

CISTERNS.

In 1876, the writer assisted his father in constructing a cistern in Pomona, Cal., which was lined with Portland cement mortar. The cistern was 7 feet in diameter and 11 feet deep, dug in a gravelly, loamy soil, and into a substratum of nearly pure sand and gravel. It was eventually coated with three coats of plaster. The plaster was composed of an imported Portland cement and sand. The proportions are not definitely remembered, but were probably about 1 cement to 3 sand. The first coat was plastered directly upon the clean cut gravel walls in a coat about ¾ inch thick. The second coat, about ¼ inch to ⅜ inch thick, was plastered over the bottom and upon the sides to within about 4 feet of the top of the cistern. The interior surface was then washed with a neat cement cream. Water was turned in and entirely disappeared in twenty-four hours. Upon examination it was found that the weight of

water had settled the bottom away from the side walls for nearly ½ inch. Another coat of plaster over the bottom and up the side walls for about 3 or 4 feet, followed by another wash of neat cement cream, remedied the trouble. The cistern was used constantly from that time until 1888, when a piped water supply replaced it. For a considerable period of time it was in service with 11 foot heads of water in it without any appreciable loss from leakage.

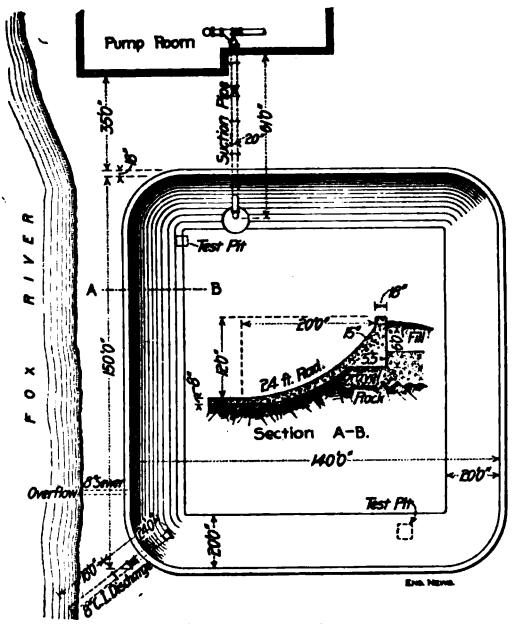
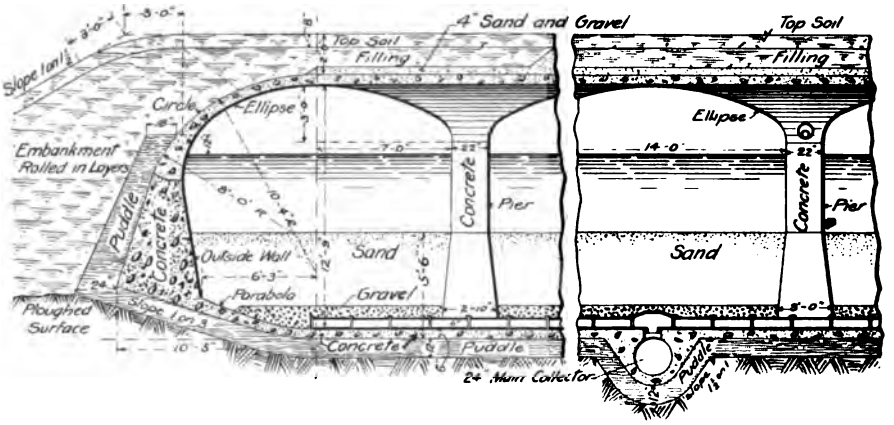


Fig. 40.—Plan of the Reservoir at Aurora, Ill.

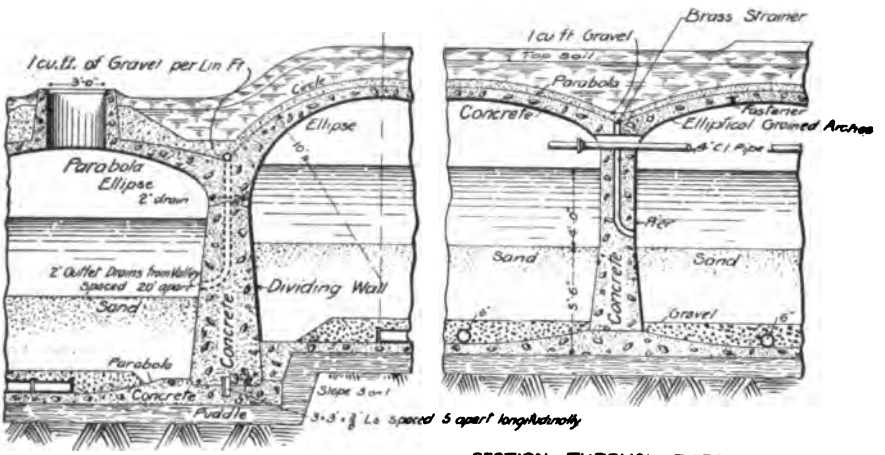
FILTER BEDS.

It is in underground structures that concrete shows to good advantage. Metal work would be subjected to serious corrosion. Brick or stone masonry would be either very expensive or else, if a cheaper quality of work and material was used, it would not be water-tight and durable. In filter beds, clear water basins, reservoirs and the like, impervious, non-corrosive materials should be used. Concrete comes nearer meeting all the requirements than any other material. For these purposes it has been extensively used for many years.

The Philadelphia filter beds illustrate its use for such purposes. The Philadelphia water system is divided into several supply stations with complete equipment at each station. For the purpose of this article it will be sufficient to describe one of the filter beds at the Belmont plant. There are eighteen filter beds at this station varying in dimensions from 166 by 196 feet to 120 by 272 feet, each filter bed covering approximately



SECTION THROUGH CROWN OF ARCH



SECTION THROUGH PIERS

SECTION THROUGH CROWN OF ARCH

Fig. 41.—Cross Section of the Filtration Chambers, Philadelphia, Pa.

¾ of an acre. These basins are built into the ground and covered over with sand, gravel and earth, and then sodded. The floors and arched roofs of concrete are about 6 inches thick. The side walls vary from about 4 feet, 2 inches thick at the base, to 12 inches thick at the spring line of the roof. The roof consists of groined arches resting upon the walls and a series of concrete piers 22 inches square at the top and 34 inches square at the base. The arches have a 14 foot span, 3 foot rise and are 6 inches thick at the crown and 21 inches thick over the piers. Over the arches are spread 4 inches of gravel to act as a draining medium to carry all collected storm water to small inlets situated over each pier, allowing the

surface percolation to be admitted to the filter beds and to be filtered with the regular supply. Concrete manholes opening to the surface are constructed at regular intervals to allow light and ventilation during cleaning and reconstruction of the sand beds. Figure 41 shows a section through the filter bed in the Roxborough plant, Philadelphia, which is similar to the Belmont plant.

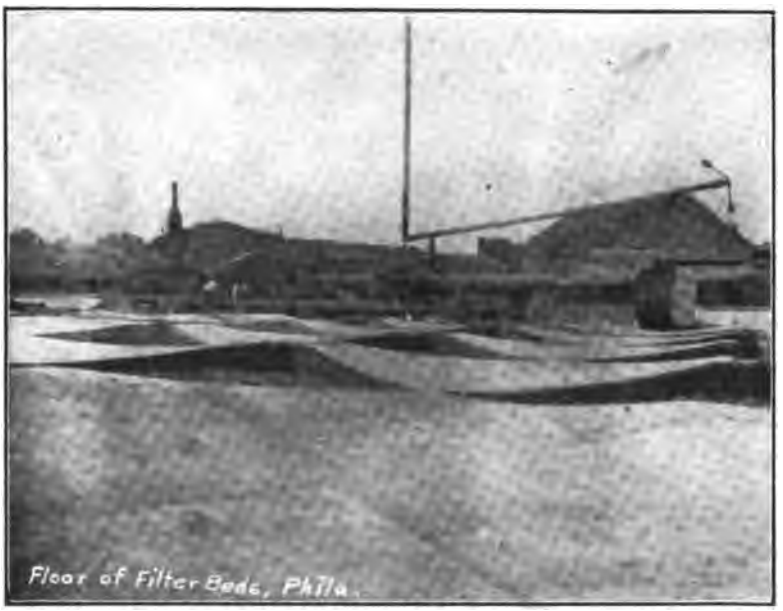


Fig. 42.—Floor of Filtration Chambers in Process of Construction, Philadelphia, Pa.

Figures 42, 43 and 44 illustrate the progressive steps in construction of the filter plant.

DAMS.

Concrete is especially useful in the construction of dams. Usually these must, of necessity, be located at points not easily accessible for securing cut stone and therefore for economy, concrete presents the best available material. Usually, however, stone is in abundance in some form which can be crushed into concrete size. It is now known that crushed stone screenings are as good as sand for a fine material to fill voids and make mortar, so that all the material requiring transportation to the site is cement. Solid monolithic structures can thus be erected with great economy.

Fig. 43.—Columns for Supporting Roof of Filtration Chambers, Philadelphia, Pa.

Otay Dam.—The Otay dam, figures 45 and 46, near San Diego, Cal., illustrate such a use of cement. This dam is 350 feet long, with a greatest height of 84 feet above the foundation. It is constructed in the

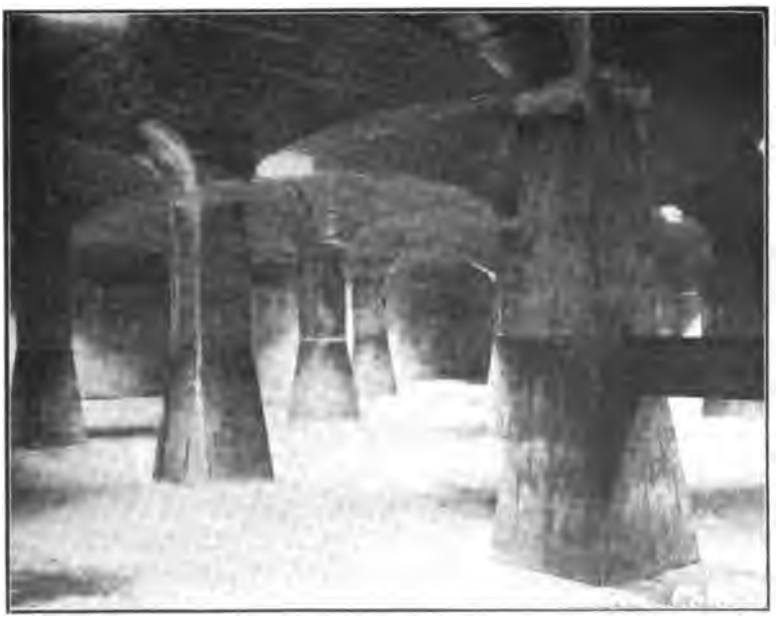


Fig. 44.—Interior of Completed Filtration Chamber, Philadelphia, Pa.

Fig. 45.—Otay Dam, San Diego, Cal.

arched form, arching up stream with a radius of 359 feet. The maximum thickness at the botttom for 14 feet in height is 24 feet, decreasing in steps until the top 5 feet is but 4 feet thick. The proportions of concrete are also graded in strength from the bottom toward the top. The bottom 31 feet is of concrete composed of 1 part cement, 2.1 parts sand and 3.4 parts crushed stone; from elevation 31 to 36 it is of 1 part cement, 3.2 parts sand and 4.2 parts stone; from elevation 36 to 75, it is of 1 part cement, 3.33 parts sand and 4.6 parts of stone. The bottom portion is reinforced for water tightness with steel plates. From the point where the steel plates cease to the top, the dam is reinforced by horizontally laid steel railway cables, 1¼ inches in diameter, spaced 2 feet apart vertically.

Las Ninfas Dam.—The United States Army officers built a concrete dam near Guatanamo, Cuba, shortly after the American-Spanish war. which stood a remarkably severe test a short time after its construction. The dam was in a narrow gorge, and was 24 feet long, 15 feet high and 2 feet thick with a straight crest. A sudden heavy rain in the hills raised the water so that it passed over the dam to a depth of 10 feet upon the crest, no damage being done. The concrete must have acted as a beam in this case to have withstood such a weight of water.

Some of the larger dams now under construction in the eastern portion of the United States are being built of concrete in which large irreg-

Fig. 46.—Otay Dam, Showing Contractor's Plant, San Diego, Cal.

ular stones are imbedded. (Figure 47.) These stones make about one-half of the volume of the dam. Such cyclopean masonry might be termed titanic concrete.

The opportunity to reduce in cost of construction by adopting open or buttressed sections in concrete, such as are described elsewhere in this article, will bring concrete more prominently to the front in the future than it has been in the past for large dams.

Apple River Dam.—Another feature of concrete is in the facing of old masonry dams or soft stone masonry cores in new dams. The Apple River dam for the St. Croix Power Company of St. Paul, Minn., illustrates its use in the latter form. This dam erected across the Apple River about 27 miles east of St. Paul, was in a very rough country where the only available building stone was a brown sandstone easily eroded by running water. It was decided to erect the core of the dam of this sandstone laid as uncoursed rubble with Portland cement mortar, composed of 1 part cement to 3 parts sand. This core was then encased with from 18 inches to 2 feet of concrete having the following proportions: 1 part Portland cement, 3 parts sand and 4 parts broken stone. The dam is 350 feet long with a central spillway 108 feet long over the crest of the dam. The dam is built in arch form up stream with radius of curvature equal to 450 feet. It is 47 feet high and has a base width or thickness of 38 feet. No cracks or leakage had appeared after a year's service. Figure 48 shows a cross section of the dam.

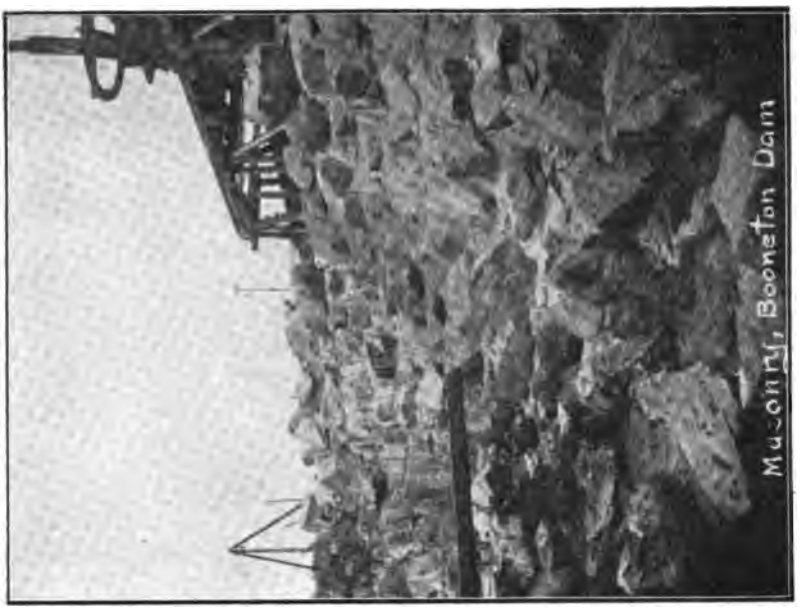


Fig. 47.—Cyclopean Masonry, Boonton, Dam.

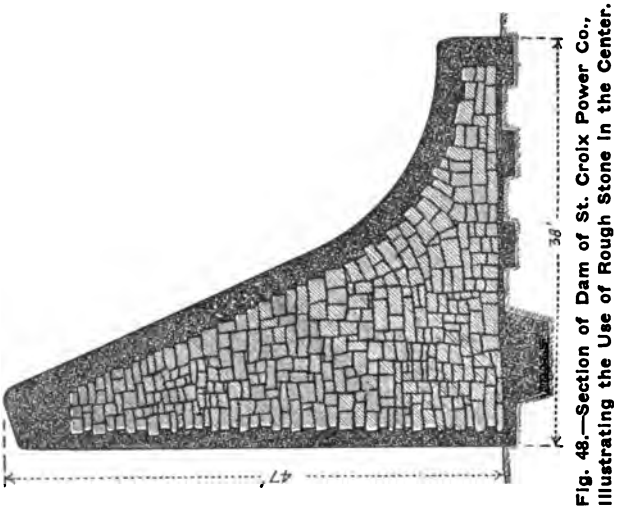


Fig. 48.—Section of Dam of St. Croix Power Co., Illustrating the Use of Rough Stone in the Center.

Birmingham Reservoir.—"The new waterworks scheme for Birmingham, England, now on the eve of completion—the greatest water scheme that has ever been attempted—a work involving the use of many *thousands of tons* of Portland cement. The water is first stored amongst the mountains in six cement reservoirs, the total storage capacity of which is 17,360 million gallons, and they cover an area of 1,499 acres. From the storage

reservoirs the water is conducted 80 miles across country, through mountains and over valleys and rivers by the aid of cement bridges, culverts, walls, tanks, tunnels, etc., to the large cement service reservoirs and filter beds shown in illustration. (Figure 49.) Of cement concrete work there are 8½ miles of tunnels, 35 miles of cut and cover, and 34½ miles of iron pipes—the cut and cover and tunnels being 8 feet in diameter.

"The site of this extensive concrete reservoir, shown above, covers a space of three-quarters of a mile in one direction and 1¼ miles in another. The walls, formed entirely of Portland cement concrete, are 16 feet thick at the base and about 35 feet in height. The water is delivered from this reservoir into a series of 18 quadrangular filter beds, ranging from 150 to 220 feet square, and forming a total filtering area of 67,000 square yards. These filtering beds are also wholly constructed of Portland cement concrete."—*Cement.*

TUNNELS.

Among some of the many tunnels in which concrete has been used as a lining, probably none will better illustrate its usefulness than the Cascade tunnel upon the Great Northern Railway located where this railway crosses the Cascade Mountains in Central Washington. The tunnel was under construction from 1897 to 1900. It is 16 feet wide and 21½ feet high in the clear. The lining varies from 24 to 42 inches in thickness and is monolithic, non-re-enforced concrete.

The concreting was done from platforms which were erected so that work trains could pass beneath. The arch was built in 12 foot sections. The centers were of planking arranged so that they could be easily moved forward and jacked up to the proper position again. Concrete plants were erected at both ends of the tunnel and were arranged to handle all the material from the crusher to the mixer by gravity. The best rock taken out of the tunnel was crushed for the concrete, the proportions of which were 1 part Portland cement, 3 parts sand and 5 parts broken stone. There were 95,000 barrels of cement used or 7 barrels per lineal foot of tunnel. The average monthly progress of lining the tunnel was 1,115 feet, with a maximum length of 1,713 feet for the best month's work. The best day's work was 32 feet of completed lining.

The total length of the tunnel is 13,813 feet. It saves nine miles of switch backs, 677 feet of elevation and 2,332 degrees of curvature. No statistics as to cost were given with this article.

Peekskill Tunnel.—A writer in Engineering News, of December 17th, 1903, gives the itemized cost of a concrete lining in a short length of tunnel upon the New York Central and Hudson River Railroad north of Peekskill, New York. He itemizes the cost under the various heads of material, lumber for forms, tools, freight, power, labor, etc., for about 2,000 cubic yards of concrete. It amounts to $10.72 per cubic yard for a

Fig. 49.—Reservoir at Birmingham, England, in Process of Construction.

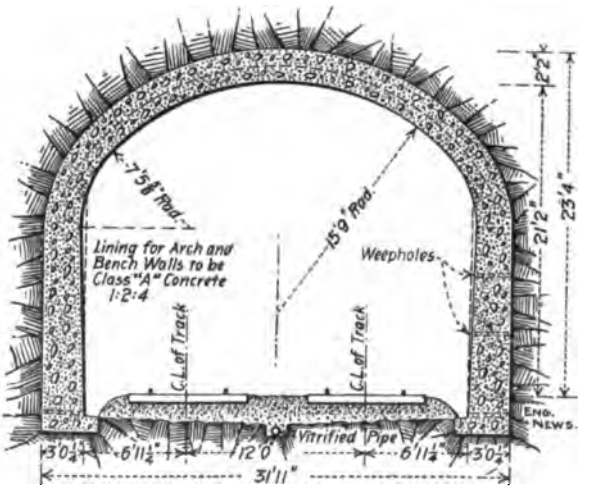


Fig. 50.—Section of Peekskill Tunnel, Showing Concrete Lining.

concrete composed of 1 part of cement, 2 parts of sand and 4 parts of broken stone. The portal head walls were of 1 part of cement, 3 sand and 6 broken stone. Figures 50 and 51 show south portal and section of the Peekskill tunnel.

Chicago Telephone Tunnels.—Perhaps one of the largest, at any rate one of the longest, tunnels ever attempted is that of the Illinois Telephone and Telegraph Company in Chicago. The trunk tunnels are 12¾ by 14 feet and the lateral tunnels 6 by 7½ feet in the clear. Their total length when completed will be about sixty miles. Up to September 1, 1902, twelve miles had been constructed and the work was advancing in fourteen headings at an average rate of 328 feet per day for completed work. About 1,500 men were employed in three shifts working eight hours each. The crown of the tunnel varies from 24½ feet to 35 feet below the surface of the street. The tunnel is being driven through stiff, blue clay without any support being required. Semi-circular draw knives are being used to cut down the clay. It is then shoveled into the cars which transfer it to the shafts where it is lifted to the street above. The ribs used for the forms are of channel iron, 3 inch channels for the laterals and 5 inch channels for the trunk tunnels. Two inch planks are used for lagging. The concrete consists of 1 part Portland cement and 5 parts crushed limestone, screenings and stone below ¾ inch in size being used, or gravel and sand being used in place of crushed stone. At curves and intersections, the concrete is strengthened by being made in proportions of 1 cement to 4 of stone or gravel. The floor is first put in place, the ribs are then set up and braced and the lagging suspended upon the frame work of ribs. The concrete is rammed behind the forms in layers and as each layer is finished, lagging is added until the key of the arch is reached—here short lagging is used and the concrete rammed into place from the end of the wall. After the forms are removed the walls are plastered to make them smooth and impervious. The floors of the trunk tunnels are 21 inches thick, with side walls 18 inches thick, while in the laterals the floors are 13 inches thick with 10 inch side walls. In the twelve miles of work done, 175,000 cubic yards of excavation have been removed and 90,000 barrels of cement have been used in the work. The tunnel was kept in most scrupulous cleanliness by the superintendent. The writer was never in a cleaner tunnel in his life. One could travel miles through the tunnel, going right into the working headings, and not soil a dress-suit nor injure patent leathers. At every street intersection street name plates are set into the concrete walls so that it is much easier to determine one's location in the tunnel than in the streets of the city above. Figures 52, 53 and 54 show a section of the completed tunnel, one of the ribbed forms for the trunk tunnel showing method of bracing the forms and a completed intersection. Figure 53 also shows the diaphragm plates used at the end of a section to keep the concrete in place.

Fig. 51.—South Portal of Peekskill Tunnel, New York.

Fig. 52.—View of Four-Way Intersection, Tunnels of Chicago and Illinois Telephone Company.

TIES AND RAIL BEDS.

The question of street and street railway maintenance in large cities has become one of increasing importance as the traffic demands have so rapidly increased during the past thirty years. The old forms of street

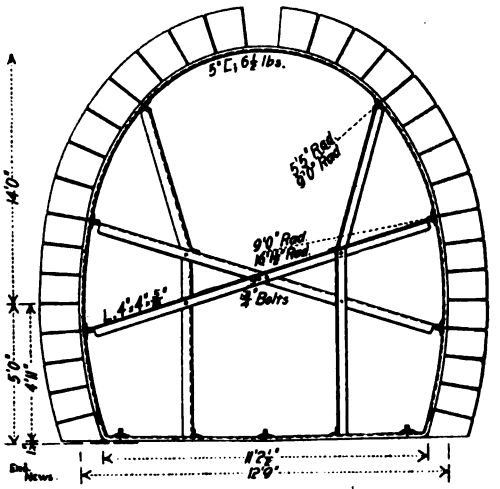


Fig. 53.—Frame and Forms for Lagging Tunnels of the Chicago and Illinois Telephone Company.

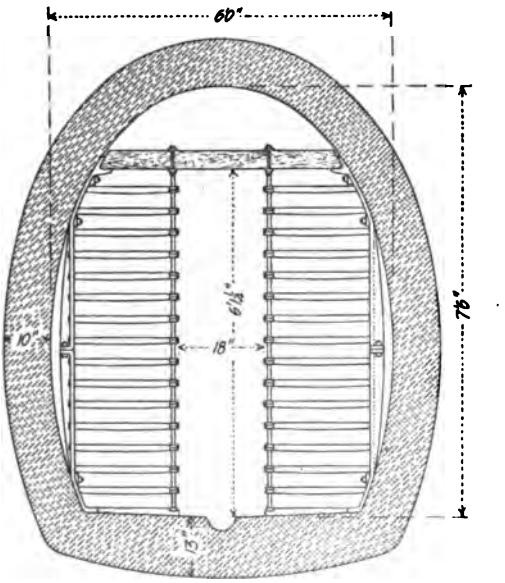


Fig. 54.—Cross Section of Finished Tunnel of the Chicago and Illinois Telephone Company.

railway construction were disastrous alike to street paving and to smooth riding tracks. Wooden ties, unsupported except by poorly tamped soils,

which, at best, could not make firm support, allowed the track to vibrate and undulate, shattering the street paving. Great opportunity was thus given for the entrance of storm water into the sub-foundation, making it still more unstable both for track and paving, until the street and track were both wrecks. To add to this, the rotting of the wooden ties required the continual tearing up of the streets in order to replace them and to keep the track in sufficient repair so that traffic could be maintained at all. Such conditions became unbearable in many of the important business streets of great cities, both to vehicle and railway traffic, and a remedy was sought. It is not necessary to follow the path of the search parties. It is sufficient to say that the remedy was found, as in many another search, in concrete.

Concrete has been used in various ways as a foundation bed for wooden ties, as stringers beneath the rails only, as concrete ties on ordinary tamped earth beds or gravel beds, and as solid concrete road beds imbedding the rail directly within the mass of concrete.

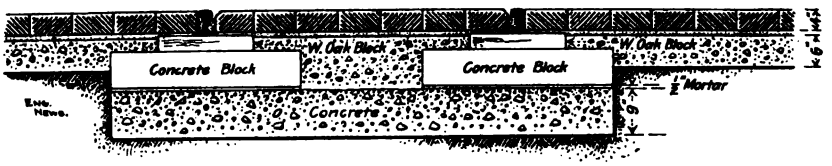


Fig. 55.—Section of Track Showing Use of Concrete Ties, Pere Marquette Railway.

† Figure 55 illustrates the form used on the Pere Marquette R. R., in Bay City, Michigan. A concrete foundation beneath the entire track is first laid, upon this, well made concrete blocks, 7 inches by 9 inches by 36 inches are laid 33 inches center to center in a bed of cement mortar and then surrounded with concrete and the concrete is carried up to within 1 inch of the base of the paving block. Upon the concrete block is placed a 3 inch white oak spiking block to which the rails are spiked. Concrete is also filled in around the web of the rail sufficiently to leave flange way between the rail and the paving block.

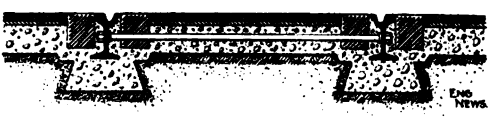


Fig. 56.—Street Railway Section Showing Concrete Rail Supports.

In Minneapolis and St. Paul, * the rail is imbedded directly in the concrete as shown in Figure 56. The rails are kept evenly spaced by metal

†*Eng. News*, Aug. 28, 1902.
Eng. News, Feb. 26, 1903.

tie rods spaced at frequent intervals. The shape of the concrete which forms the rail bed is varied by different engineers, but the same result is obtained. The track and paving become one solid whole. The following estimate of the cost of one mile of such track, using a grooved rail, is given by Mr. B. J. Arnold, M. Am. Inst. Elec. E. Many of the prices used in the estimate will vary, of course, according to the market and local conditions; this estimate was made for Chicago, early in 1903.

Estimated Cost of One Mile of Grooved Rail Track with Concrete Beam Support.

Excavation and hauling, 2,000 cu. yds. at $1.00	$ 2,000 00
Concrete beams, 800 cu. yds. at $6.00	4,800 00
Steel rails, 120 lbs. per yard, 188.57 tons at $41.00	7,731 00
Hauling rails to street at $1.00	189 00
Tie rods, 700, at $0.25	175 00
Cast welded joints, 176, at $5.00	880 00
Cross bonding	10 00
Track laying, cleaning street, etc.	1,501 00
Special track work per mile of single track	4,500 00
Engineering, supervision and administration at 10%	2,179 00
Total cost of track exclusive of paving	$23,965 00

ROAD FOUNDATIONS

For years concrete foundations for paved streets have met the decided approval of municipal engineers. The engineer who fails to consider the foundation to be one of the most important essentials of a well paved street fails to secure economy and durability in the streets he paves. Better an inferior wearing surface upon a first class, solid, impervious foundation, than a high grade wearing surface upon a yielding pervious foundation. In the first case only the wearing surface needs renewing after a short period, while in the latter case the whole construction including the road-bed must be overhauled in order to secure a decent street. Of all the foundation materials employed, none so nearly meet all the requirements as does well laid concrete. It is rigid, distributing the load of traffic to a large bearing surface of soil; being rigid, it does not allow deformation of the wearing surface and the consequent abrasion due to such deformation; it prevents water reaching the soil of the road-bed, and thus the subgrade gives firm support to the foundation. It is easily and perfectly repaired when it becomes necessary to cut into a street for subsurface connections of any kind. It is durable to the maximum limit of man's observation. It is not much more expensive than a well rolled broken stone or gravel foundation, which is next in importance for such purposes.

The thickness required varies from 4 to 8 inches according to the traffic and to the character of the subsoil. Six inches is the usual depth

and for all ordinary circumstances this is ample if good concrete is used. Both natural and Portland cements are used for foundation work, but the writer prefers to use Portland cement. Different engineers vary greatly in the proportions used. The character of the soil beneath has some weight in the choice of the proportions.

With natural cements these proportions may vary from 1 cement, 2 sand and 3 stone, to 1 cement, 3 sand and 6 stone. When Portland cement is used, the limits are from 1 cement, 2 sand and 5 stone, to 1 cement, 5 sand and 10 stone. Under all conditions the writer should prefer to use a richer mixture than the last named limit. The concrete should be well mixed and compacted, and rather wetter than concrete used in walls.

Some of the later concrete foundations put down in Columbus, Ohio, have been of 1 cement, 4 sand and 8 broken stone; these proportions appear to make an excellent foundation.

Figure 57 shows a section of Tenth avenue, Columbus, Ohio, which is paved with brick block upon a concrete foundation. This concrete foundation costs from 70 to 75 cents per square yard. The labor of mixing and laying the concrete cost on an average 15 cents per square yard.

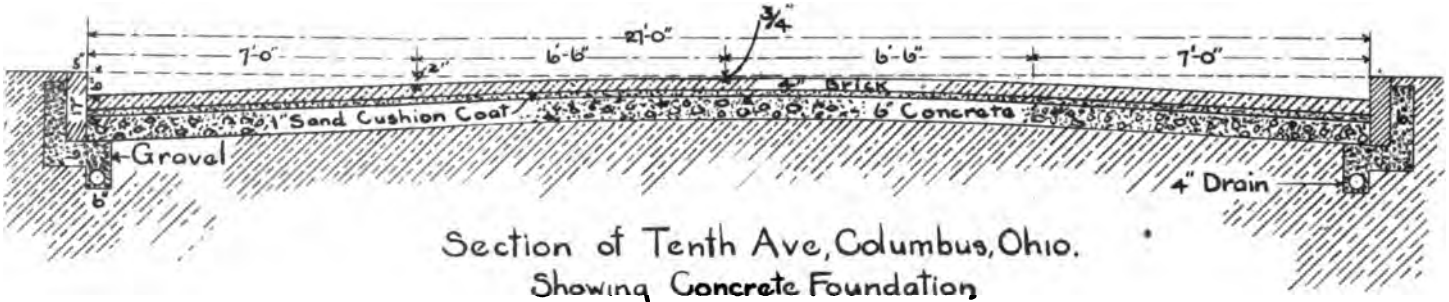
The cost of concrete foundation was carefully kept in Toronto, Canada, as follows:

	Cost per cu. yd.
Cement at $2.77¾ per bbl.	$2.15
Broken stone at $1.91 per cu. yd.	1.43
Gravel and sand at $0.80 per cu. yd.	0.21
Labor at 15c. per hour	1.04
Total per cu. yd.	$4.83

Or, with concrete six inches deep, 80½ cents per square yard.
The concrete used in this case was 1 cement, 2½ sand and 7½ stone.

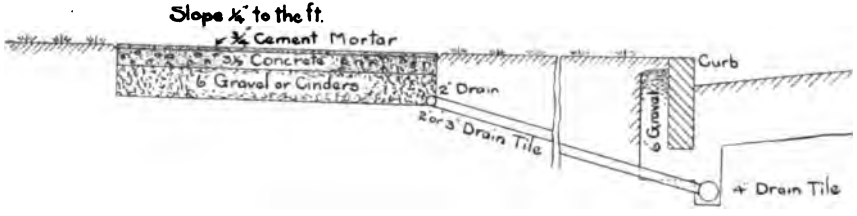
PAVED STREETS.

While concrete has not been used extensively as a surface paving material for streets, it has been used quite satisfactorily in some alleys in Philadelphia, a couple of streets or courts in Grand Rapids, Mich., and on four streets at Bellefontaine, Ohio. The streets in Bellefontaine were laid in 1892 and 1893, and are in excellent condition today. The concrete was laid upon a well compacted road-bed in two layers, the foundation layer 4 inches thick, and the surface layer 2 inches thick. In two of the streets the foundation concrete was composed of 1 part Portland cement to 5 parts coarse gravel, and the surface coat 3 parts cement to 5 parts coarse sand. In the other two streets the proportions were: Foundation, 1 cement to 4 parts gravel, and surface coat, 1 cement to 1 sand. Both top and bottom layers were cut into blocks about 5 or 6 feet square and tarred paper used in the joints to give room for expansion. The sur-



Section of Tenth Ave, Columbus, Ohio.
Showing Concrete Foundation

Figure 57.



Section of Concrete Sidewalk

Figure 60.

face layer after being thoroughly rammed and floated was indented with an imprint roller in order to give a better foothold for horses. While some repairs have been made, the streets do not show any patchy appearance and along the sides the surface has not worn enough to obliterate the imprint marks which are clearly shown in figure 58. The worst worn place in the streets is shown in Figure 59 where the street was narrow and drained toward the center. Here the wheels have followed in the lines cut to demark the blocks, and have worn the cutting lines about 2 inches deep. The streets cost $2.15 per square yard. There appeared to be no complaint against the streets on account of slipperiness or because of the jar or lack of elasticity. Such streets are easily cleaned and dry up quickly after storms.

Fig. 58.—Concrete Pavement at Bellefontaine, Ohio. In the Foreground Will Be Seen Surface Marks Not Destroyed After Years of Use.

SIDEWALKS.

Concrete sidewalks have been used many years. There is no one of the requirements for a good sidewalk which concrete does not completely fulfill. It makes a smooth walk and yet it is not slippery. It is durable, wears evenly, does not absorb water seriously, dries up very quickly, does not glaze over with ice as quickly nor as completely as does brick, does not flake up nor disintegrate under action of frost. In fact, it is ideal. In some cities there is a prejudice against concrete walks because unprincipled or ignorant contractors have done poor work, and like poor work in any business, it has not proved satisfactory. Wherever

proper work has been done, concrete walks have grown in favor very rapidly. In some towns ordinances have been enacted requiring concrete walks and not allowing any other kind of walk to be laid within their limits. A good concrete walk should have a 3½ inch base with a one inch wearing surface. Upon gravelly or well drained soil this will be sufficient, but in clayey or heavy soils it is best to construct the walk with a subfoundation consisting of from 4 to 10 inches of well compacted gravel or cinders.

Fig. 59.—Concrete Pavement at Bellefontaine, Ohio, Showing Longitudinal Wheel Marks.

Drainage is also necessary in heavy soils in order to prevent heaving of the walk during the winter weather. Another precaution that should be observed is to cut the walk into blocks about 5 feet square, taking pains to cut entirely through both foundation and surface layers, so that any heaving from frost or settling due to poorly compacted sub-bed, will not break the individual stone, but simply move the block at the cutting line. The attempt to cheapen the work by using a natural cement for the base and a Portland cement in the wearing surface is ill-advised economy.

It is quite questionable whether a perfect union between the two masses of concrete can be secured. The gain in cost is so small when the question of the greater allowable proportion of aggregate with the Portland cement over that with natural cement is considered, that it does not pay to risk the character of the work to make the gain.

The cost of cement walks, well constructed, in 1896 to 1898, varied from 11 to 14 cents per square foot. In 1902 and 1903, prices of material and labor being higher, the same class of work cost from 14 to 17 cents per square foot.

As to the life of a first class concrete walk, there appears to be no limit. The writer knows of one walk that has been down some twenty-one years or more that is as good today as the day it was laid.

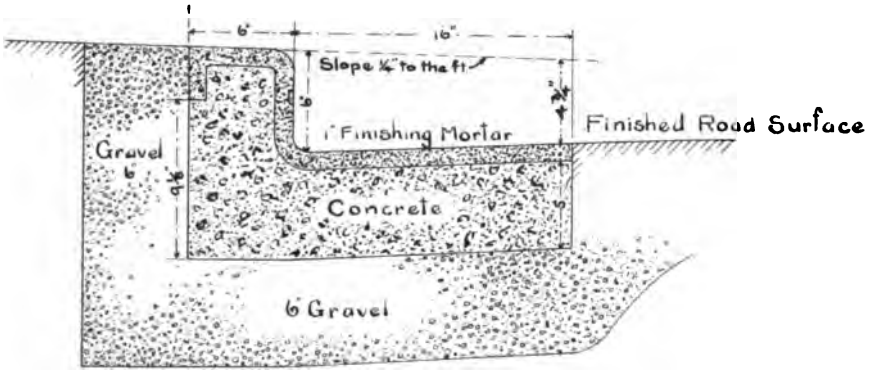
Fig. 61.—Concrete Sidewalk Built in 1880 at Conneaut, Ohio.

One of the walks along the Capitol Block in Indianapolis has been down over thirty years. It was constructed of excellent material, but with no special attention to the preparation of the sub-bed, consequently water has percolated into the soil beneath and heaved the blocks badly and they have become broken. The blocks are cut about 18 or 20 inches square with lines running diagonally across the walk. Where they have had reasonable support, however, they are still in good condition. If

the walk had been constructed as the better class of walks is today, it would have remained in perfect condition. It seems almost incredible to believe that people can go on year after year stumbling over miserably irregular brick walks, when smooth, regular concrete walks are obtainable. Figure 60, page 112, shows a section of a concrete walk. Figure 61 shows a well preserved old concrete walk.

CURBS AND GUTTERS.

A much later application of concrete than that of sidewalk construction is its use for curbs and gutters. So many of the natural stones when used for curbs absorb water and disintegrate under frost action. Limestone is especially subject to disintegration because of its lamination. Sandstone wears rapidly at points where wheels rub. In some parts of our country neither limestone nor sandstone can be obtained at a reasonable price, thus the demand for some good substitute has arisen.



Section of Combined Concrete Curb & Gutter

Figure 62.

It has been found very easy to put in the plain concrete curb, and it has proved very durable and at the same time has added much to the appearance of the street. Another problem that the road engineers have had to solve is the building of a gutter that will be smooth enough not to retard the flow of storm water upon very flat grades and at the same time so impervious, durable and tough that it will not rot out under continued dampness nor wear out quickly under usage. Cobblestone, brick and stone block retard the flow of water. Asphalt and coal tar rot or disintegrate under the action of water. Concrete once more fulfills all the requirements. By combining the curb and gutter into one monolithic whole, several difficulties are avoided. The displacement of the curb, due to frost upon one side or the expansion of the street upon the other, is greatly reduced. Shrinkage and expansion do not cause cracks along the face of the curb,

thus allowing storm water to seep into the foundation and road-bed to create havoc. Debris, which usually collects in the gutters, is more easily carried along by the storm water, hence a cleaner looking street is the result. The general appearance of a combined curb and gutter is more pleasing to the eye. So once more concrete has found an opportunity to usurp the place of other building material. Figure 62 shows a section, with average dimensions, of a combined curb and gutter as used upon Ninth avenue, Columbus, Ohio. Such a curb and gutter costs about 75 cents per lineal foot.

FENCE AND FENCE POSTS.

Around the old village of Woodruff Place, now within the corporate limits of the city of Indianapolis, is a concrete fence, not a wall, but a fence with posts and stringers with large concrete balusters or palings. The posts are about 24 inches by 36 inches in cross-section and 4 feet high set every 10 feet. A top rail 20 inches wide and 8 inches thick runs from post to post, with a base rail quite near the ground. Connecting the two rails and spaced 18 inches center to center are ornately shaped balusters. The fence is not in the best of repair, but it has been in place for thirty years or more and is in fair condition considering its age and the probable manner of construction.

POSTS.

At the zoological garden in Washington, the officers in charge have put concrete bases on the iron posts which are to be used in fencing in the larger wild animals. The advantage is very apparent. Iron would rust out quickly, and having rusted, might give way at some time without any warning, allowing valuable or dangerous animals to get away. With the concrete base upon the post several things are gained. First, the enlarged base gives more firmness to the post; second, the iron below ground is protected from moisture and from action of soluble chemicals in the soil, and third, as the concrete comes to the surface the post above the concrete is open for inspection and any weakness or corrosion can be detected before harm is done. These posts consist of small iron pipes or bars set in the center of the concrete bases which are 12 inches square and 24 inches deep.

MILE POSTS.

The Chicago and Eastern Illinois Railroad * has adopted a concrete mile post. The post is 8 inches square and 8 feet long, standing 4½ feet out of the ground. The figures are 3½ inches high and the letters 6 inches high, both being recessed ¼ inch into the post. The post weighs 498 pounds.

The sides of the form are plastered ½ inch thick before the ordinary concrete is put in. A special feature of the post is that the face contain-

*Eng. News, Jan. 1, 1908.

ing the letters is plastered with neat cement colored black by the addition of ¼ pound of lamp black to 1 quart of cement mixed in water. The letters and figures are then painted white. The concrete is composed of 1 part cement, 1 part sand and 2 parts crushed stone.

The cost of the post is as follows:

¼ barrel of cement, at $2.00	$ .50
267 pounds of crushed stone	.01
133 pounds of sand	.01
1⅓ hours of labor, at 15c	.20
Carpenter, changing letters, ⅓ hour, at 25c	.08
Coloring in cement	.02
Total cost of post	$ .82

Figure 63 illustrates this post.

There are now several post manufacturing concerns which make concrete posts, but all are reinforced by steel and will be described in the next chapter.

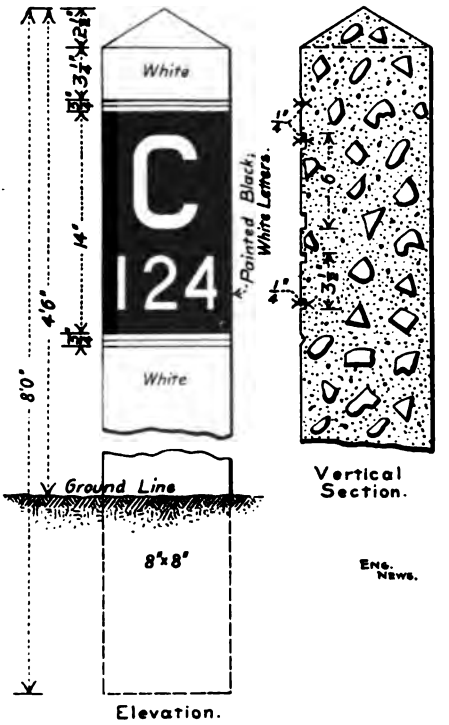


Fig. 63.—Concrete Mile Posts on the C. & E. I. Railroad.

TELEGRAPH POLES.

The manufacturing of concrete butts for telegraph poles is one of the latest novelties in the use of cement. It is well known by those who

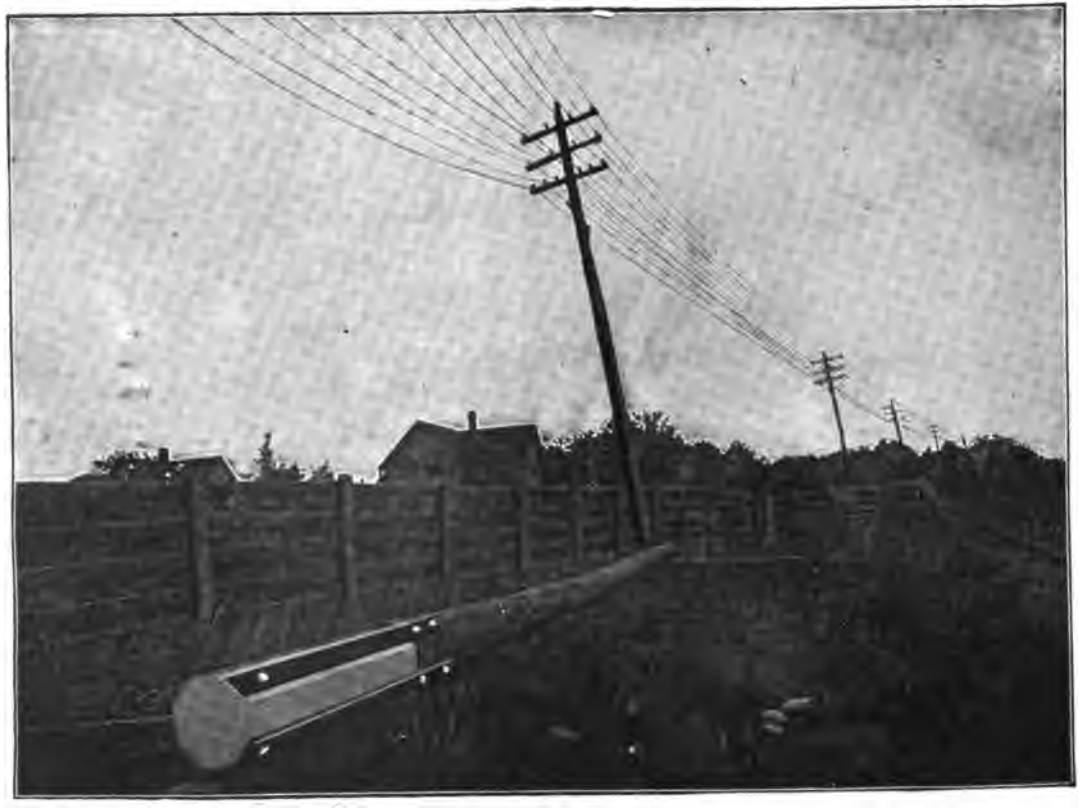


Fig. 64.—Concrete Butt for Telegraph Pole.

are observant that when telegraph or telephone poles have to be replaced, it does not always mean that the whole pole has rotted away, but just that portion sitting in the ground. Sometimes the poles can be removed to a country line and reset by having the base sawed off; the balance of the pole being perfectly sound. The cost of renewing poles, rewiring, etc., is expensive. To avoid much of that trouble and expense this industry provides concrete bases cast in octagonal forms with four iron strips bolted to opposite faces extending a foot or more above the concrete. The rotten butt of the pole can then be sawed off, the pole set a couple of feet to one side, the concrete butt set firmly in place and the pole set into the socket between the iron strips and firmly bolted to its new base. No wiring need be touched nor communication interrupted in the least. The pole when thus equipped is better than new, because it will not rot out at the base again. If from extreme age or from special disaster the poles need replacing, poles five feet shorter than otherwise required can be used, thus adding materially to the amount saved. Such concrete butts have been in use for three years, giving good satisfaction. Figure 64 shows such a butt bolted to a pole.

BURIAL VAULTS.

Concrete burial vaults are being made, in sections, so that they can be shipped to any point, set up in cement, and thus provide water-tight and nearly air-tight receptacles for the casket. The pieces are not large, so that they are easily handled. They are are all grooved and ribbed so that they fit together well, and neat cement paste is used in all the joints to make a perfectly tight vault. The roof is made in arched form with beveled edges fitting into the V shaped bevels upon the top end of the side pieces.

The inventor claims two objects are served by this kind of a vault: A better protection to the bodies of the dead, and a sanitary safeguard provided for the living. It serves one of its most useful purposes in the exhumation and reinterment of bodies. It is not so cumbersome but that it can be moved bodily without removing the interior casket, the cement-joints and the bevel rib feature making the vault one solid piece of stone to be moved. Figure 65 illustrates the Lyon's burial vault, the shape of the pieces, and the method of fitting them together.

FURNITURE.

Mr. W. N. Wight of Westwood, N. J., has still further extended the use of concrete by making various articles of house and stable furniture. Among the articles is an ice chest with an opening to put in the ice from the outside of the house, while the provisions and food are placed in the cooling chamber from within the house. Another article is a concrete fruit closet for canned goods. Outside, he has built a neat dog

kennel which is comfortable, durable and easily kept in sanitary condition. At his stable, he has constructed a concrete stove on which to cook the food for his stock. In all this work he has used woven wire netting with a concrete of 1 cement, 2 sand and 5 cinders.

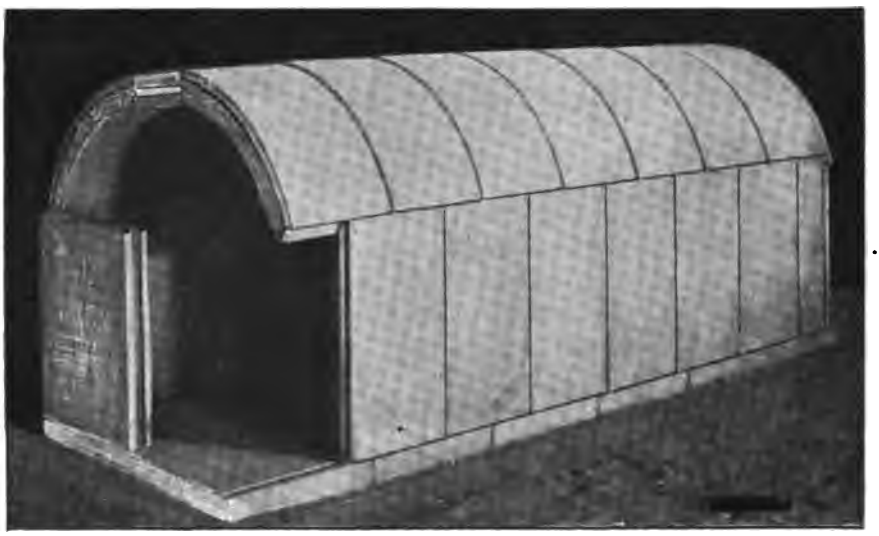


Fig. 65.—Concrete Burial Vault.

COEFFICIENT OF EXPANSION OF CONCRETE.

† From 1899 to 1901, Prof. Wm. D. Pence, of the Purdue University, Lafayette, Ind., with several of his students, carried on a series of tests to determine the coefficient of expansion for concrete. It was planned with special reference to the use of steel with concrete. The composition of the concrete was based upon the specifications of Mr. Edwin Thacher, M. Am. Soc. C. E., for a concrete for use in concrete steel construction: namely, 1 part cement, 2 parts sand and 4 parts crushed stone that will pass through a 1¼ inch ring. Lehigh Portland cement was used the first year and Medusa Portland the second. In the first series of tests Bedford oolitic limestone was used and in the second, Kankakee, Illinois, limestone was used. A bar of unbroken limestone was also tested in the second series.

"In the plan finally adopted a standard bar of steel or copper with known coefficient of expansion was subjected to identical changes of temperature with the test bar of concrete, and the difference of expansion of the two bars was determined by the principle of the 'optical lever.' This difference in length, reduced to a unit of length and temperature, gave a correction to be applied to the known coefficient of the metal bar."

†"*Eng. Record*, Feb'y. 22, 1902."

The results obtained were as follows:

Coefficient of expansion of gravel concrete, 0.0000054 per degree F.
Coefficient of expansion of broken stone concrete, 0.0000055 per degree F.
Coefficient of expansion of limestone bar, 0.0000056 per degree F.

The coefficient for concrete may be conveniently remembered as "five zeros fifty-five."

As the coefficient for steel is, closely, 0.000006o, the variation between steel and concrete is not sufficient to seriously affect their use in combination.

COST OF CONCRETE.

There are so many conditions, local and general, that enter into the cost of concrete, that but brief space will be taken up here to give a few instances of the actual cost of concrete for various purposes and in widely different localities. The prices of labor and material and the ease or difficulty of access to material and the work to be done, largely govern the cost of concrete.

TABLE No. 20.

Cost of Concrete—Using Portland Cement.

Date.	Location.	Class of Work.	Proportions.	Cost per cubic yard.	Remarks.
1880–85	Newhaven, Eng.	Breakwater	1–7	$5.50	Laid in sacks.
1889	Buffalo, N. Y.	Breakwater		9.19	
1891	Buffalo, N. Y.	Breakwater		8.21	
1900–02	Buffalo, N. Y.	Breakwater	1–3 –4	5.65	
1900–02	Buffalo, N Y.	Breakwater	1–3 –4	6.64	
1890–91	Toronto, Can	Road Foundation	1–2. –7½	4.83	
1895	Marquette, Mich.	Breakwater	1–2½–5	6.35	
1899	Marquette, Mich.	U. S. Breakwater		4.57	Eng. News Feb.17,'98. Gov't and contract work.
1889	Buffalo, N. Y.	Harbor Work		8.75	
1898	Gr. Kanawha, W. Va.	RiverImprov'ment		7.25	
1897	Monongahela River.	Lock and Dam		11.00	
1898	Chicago, Ills.	Sidewalks.	1–2 –5	10.00	Approx.

TABLE No. 20—Concluded.

Date.	Location.	Class of Work.	Proportions.	Cost per cubic yard.	Remarks.
1903	Chicago, Ills.....	Sidewalks.....	1–2 –5	12.50	Approx.
1899	Columbus, Ohio.....	Levee.....	1–2½–5	5.75	Work by day labor.
1889	Columbus, Ohio.....	Dam.....	.....	4.95	Average of ten bids.
1900	Chicago, Ills.....	C. & N.W. Ry.....	1–3 –4½	4.81	Track Elevation.
1902	Chicago, Ills.....	L. S. & M. S. Ry..	1–3 –6	6.25	Retaining Wall.
1903	Peekskill, N. Y.....	Tunnel.....	1–2 –4	10.72	Lining of Ry. Tunnel.
1903	Columbus, Ohio.....	Road Foundation.	1–4 –8	4.35	
1904	Columbus, Ohio.....	Curb and Gutter..	.....	17.00	Approx.

TABLE No. 21.

Cost of Concrete—Using Natural Cement.

Date.	Location.	Class of Work.	Proportions.	Cost per cubic yard.	Remarks.
1895	Marquette, Mich.....	Breakwater	.....	3.64	Government River and Harbor Work.
1894	New York.....	Harbor.....	.....	3.55	
1897	Rough River, Ky.....	River Impr'v'm'nt	.....	7.50	
1897	Herr's Island, Allegheny River	River Impr'v'm'nt	.....	3.59	
1897	Monongahela River.....	River Impr'v'mn't	.....	8.00	
1900	Chicago, Ills.....	C. & N. W. Track Elevation	1–2 –3½	2.40	Including Forms.
1902	Chicago, Ills.....	L. S. & M. S. Ry..	1–2 –4	4.00	Foundation of Wall.

The cost of massive concrete can be materially reduced in price if large irregular boulders or stones are imbedded in the concrete. It is possible to do this without in any way weakening the mass. If concrete cost $6.00 per cubic yard and stone costing $1.00 per cubic yard was imbedded in the concrete to the extent of say 40 per cent. of the mass, then one cubic yard of masonry would cost $4,00, a saving of one-third the cost of the original concrete.

CHAPTER IV.

THE USES OF CEMENT IN REINFORCED CONCRETE.

"Reinforced concrete," "Armored concrete," or "Steel concrete" as it is variously called, is the structure resulting from the use of concrete with iron or steel ribs or "bones" running through the concrete mass.

EARLY USE OF REINFORCED CONCRETE.

Condensed extracts from a discussion upon Steel Concrete Construction by Mr. A. L. Johnson, Assoc. M. Am. Soc. C. E., printed in the Proceedings of the American Society of Civil Engineers, follows. He gives to Mr. W. E. Ward the credit of having first used steel reinforced concrete in a scientific manner in a building which he erected in Port Chester, N. Y., in 1875. Mr. Ward constructed a building in which "not only all the external and internal walls, cornices and towers were constructed of beton (the word concrete was not then in use), but all the beams and roofs were exclusively made of beton reinforced with light-iron beams and rods."

"Francois Coignet of Paris, in 1869, took out patents on a combination of beton and iron rods, but he had no conception of the proper method of using the materials."

Monier built his first wire and beton flower pots in 1876, but the manner in which he combined the two materials showed that he did not understand the principles of reinforced concrete. He placed the wire webbing in the neutral axis of the slab; while it answered his purpose, it would be disastrous to attempt such construction upon beams or in bridges.

Thaddeus Hyatt, of England, began experiments upon reinforced concrete in 1876, the result of which he published in 1877.

It is probable that the first approximately correct formulas for reinforced concrete were derived by Julius Mandl in Germany, and Prof. J. B. Johnson in this country at about the same time.

L. A. Saunders, engineer for Monier construction, in Germany, published an extensive treatise upon the subject. In 1899 M. Considere, Ingenieur en Chef des Ponts et Chaussees. Paris, published a long discussion upon Ciment-armé. "His studies embraced the following points:

Geometrical and algebraic determinations of the moment of resistance of armed pieces, influence of the quality of the concrete and of the armatures, the most economical percentage of metal, effect of bad workmanship, value of the factor of safety, and the utility of symmetrical armatures." In more recent years Edwin Thacher has published from time to time the results of a careful mathematical investigation of the theory.

RECENT USE OF REINFORCED CONCRETE.

During the last four or five years many different systems have been developed, few of which have introduced any radical ideas into reinforced concrete construction.

Concrete has great compressive strength, but lacks reliable, uniform tensile strength. Engineers have sought to take advantage of the strength of concrete in compression for all classes of construction, but to do so they must insert some material to supply the much needed tensile strength, hence they have imbedded steel and iron bars of various sizes and shapes, in the various positions in the concrete mass where they conceive the tensile strains will occur. Tests have proved conclusively that greatly added strength has been given to such structures.

Professor W. K. Hatt,* Purdue University, Lafayette, Ind., has carried on a series of tests with his senior students which very clearly show the effect of reinforcing concrete beams. Concrete beams 8 by 8 inches square were tested in lengths of 80 inches between supports. The several beams were reinforced by ⅝ and ¾ inch iron bars placed 1 and 2 inches from the lower face of the beam. The majority of the tests were made upon concrete composed of 1 part cement, 2 parts sand and 4 parts broken stone. A few tests were made upon cinder concrete and some with gravel concrete. The variables tested were age, per cent. of steel, position of steel and material.

One per cent. of reinforcement placed 1 inch from the bottom increased the strength of the plain concrete beams from 2,200 to 7,400 pounds, and increased the flexibility of the beam from a center deflection of 0.01 inch to 0.14 inch.

Two per cent. of reinforcement increased the strength from 7,200 to 10,000 pounds with only a slight increase in the flexibility. Raising the 1 per cent. of metal 2 inches from the bottom face decreased the strength from 7,200 to 5,000 pounds, with a slight decrease in flexibility.

"A cinder concrete and a stone concrete beam each reinforced with 2 per cent. of metal, 1 inch from the bottom face, had comparative strengths of 5,000 and 10,000 pounds, respectively, and a comparative flexibility of 0.26 and 0.16 inch, respectively. In case of plain cinders and stone concrete beams, the comparative strength was 600 and 1,800 pounds, and

Eng. News, July 17, 1902.

the flexibility was 0.023 and 0.016 inch, respectively. "It thus appears that reinforcing a beam with even 1 per cent. of steel gives it ten times its former flexibility and more than three times its former strength."

In plain foundations or heavy walls where concrete is only used in compression, and no transverse or tensile strains are brought upon the structure, there is no need for reinforcing concrete, for it has such great resistance to compression that it is as strong as can be desired for such work.

It is in beams, floors, light walls, roofs, bridges, arches, and a thousand other places where it is desirable to use concrete because of its many good qualities, but where it is placed in tension, that reinforcement becomes necessary. The qualities for which concrete are sought are, non-corrosion in moist places, non-rotting under any condition, resistance to fire, resistance to weathering, deadening of sound, ease of construction, especially by unskilled labor when directed by a few competent skilled men, cheapness compared with other stone of equal appearance, and its durability.

There are nearly as many systems of steel reinforced concrete as there are men who have attempted that kind of construction. The general theory is the same in each system, namely, that all transverse or lateral strains affect the material the same as such strains affect a beam; that is, by placing the fibres or material on the side from which the force is acting under compression and on the opposite side under tension.

As the concrete is an exceptionally good material for compression it needs no reinforcing upon the compression side, but as it is a poor material for tension, metal tension members are inserted upon the tension side. The systems fall into three classes, those that use expanded metal, those that use wire mesh and those that use iron or steel bars in some one of the various forms. Of the latter class, nearly every conceivable shaped bar is used—flat, round, square, twisted and special rolled shapes.

DANGERS FROM CORROSION.

One of the questions that the advocate of reinforced concrete must meet satisfactorily is, "Will your iron or steel members remain safe from corrosion and consequent weakening for an indefinitely extended time under all conditions?" There seems to be little doubt among cement users that when neat cement mortar or a sand mortar rich in cement is used there will be no danger from rust, but when cinders or open material or lean concrete is used they fear there will be corrosion. Stone, Carpenter and Willson, architects of Providence, R. I., are quoted as having inspected a five story steel skeleton building which was torn down after five years' service. The outside columns were surrounded with brick, the interior columns protected with wire lathing and hard plaster. The floors were of expanded metal and cinder concrete. Before destruction,

the floors were tested to 900 pounds per square foot. The general appearance of the columns was as good as when put in place. The expanded metal which was protected by cinder concrete showed a little rust in a few places, but not enough to give any apprehension. In fact, they said it appeared to have ceased rusting long ago.

Pabst Hotel, New York.—The Pabst Hotel, at the corner of Broadway and 42nd street, N. Y., was built in 1898 and torn down in 1903. The metal enclosed in concrete and terra cotta showed some rust, about as much as would occur while the concrete was thoroughly using all the water within it. This was a cinder concrete and quite porous.

World's Fair Specimen.—The writer, who was engaged at the Exposition Grounds throughout the building and operation of the World's Columbian Exposition at Chicago, saw the construction in 1892 of the cement exhibit of the Alsen Portland Cement Company. One portion of their exhibit was a concrete pedestal upon which were two large concrete figures, one of which held aloft a banner bearing the Alsen's advertisement. The writer visited Jackson Park in the summer of 1902 just as the final destruction of the statue occurred. It had long been broken down, but was then being broken into smaller pieces to act as filling along the embankment of a lakelet. While breaking up the head of this figure, a screw used as a holding pin by the artist who made the statue was brought to view. It was in excellent condition; a large portion of the surface came out of the concrete as bright and untarnished as the day it went in. A small part of the threaded portion which had not been intimately in contact with the cement showed a coating of rust; about as much as would have occurred if the screw had been wet and lain exposed for two or three days. This screw had been in service ten years, and for several years the head of the figure in which the screw was imbedded had been lying in the marshy sand at the south end of Jackson Park. A longer test would not have proven more conclusively that dense concrete protects steel against corrosion.

Norton's Experiments.—Prof. C. H. Norton, engineer of the Insurance Engineering Experiment Station, Boston, made a series of tests with steel and iron imbedded in cement, concrete and cinder concrete to determine the effect of the different classes of concrete upon the metals as to danger of rusting. Two brands of cement were used—neat, and with sand, stone and cinders. Concrete bricks 3 inches by 3 inches by 8 inches in dimensions with three specimens of steel in each, a rod of mild steel 6 inches long and ¼ inch diameter, a bar of soft sheet steel 6 inches by 1 inch by 1-32 inch, and a strip of expanded metal 6 inches by 1 inch in size respectively were used in each brick. He subjected these bricks to different conditions as follows: Some were subjected to steam, air and carbonic acid, some to air and steam, some to air and carbonic acid and one-fourth

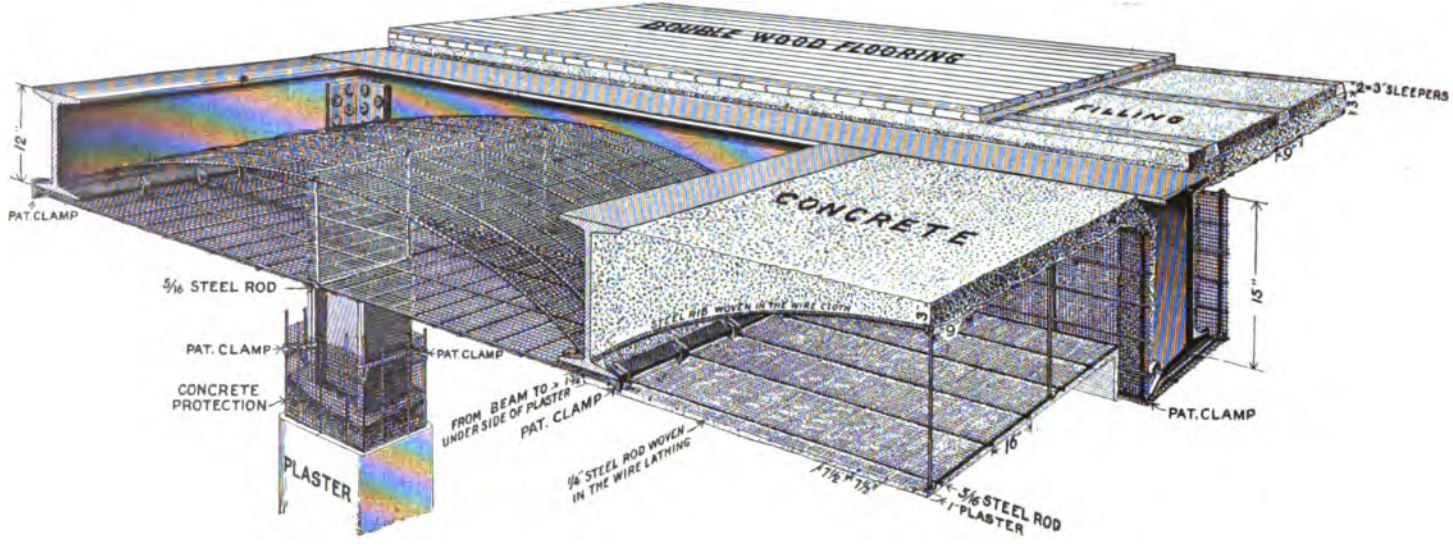


Fig. 66.—Roebling System A Arch Construction.

of the number stood in the air of the room. At the end of twenty-one days all were cut open. Unprotected steel subjected to similar tests was badly corroded. In the concretes wherever a crack or a void occurred the steel was more or less corroded. In neat cement no corrosion showed. Prof. Norton's conclusions are:

1st. Neat cement thoroughly prevents rust.

2nd. Concretes should be dense and without voids and mixed quite wet to prevent rusting the metal.

3rd. Corrosion found in cinder concrete is mainly due to iron rust in the cinders and not to the sulphur.

4th. Cinder concrete free from voids and well rammed wet is nearly as effective as stone concrete.

5th. It is of the utmost importance that the steel should be clean when it is imbedded.

THE ADHESION OF CONCRETE TO METAL.

The necessity of taking additional precaution for preventing the separation of the metal and the concrete when placed under great strain is viewed quite differently by the various experts in reinforced concrete construction. Prof. Bauschinger of Germany determined by a series of tests that steel or iron and cement adhere to the extent of 625 pounds per square inch of surface. Messrs. Krumm and Senter, civil engineering graduates of the Ohio State University, found by a series of tests that one inch iron rods set 12 inches into neat cement mortar after 22 weeks, required a pull of 530 pounds per square inch of imbedded surface to draw them out. In a mortar of 1 cement to 1 sand, 12 to 16 weeks of age, it required from 723 to 772 pounds per square inch of adhering surface to extract the rods. Assuming the tensile strength of iron or steel at 60,000 pounds per square inch and the adhesion of cement mortar to steel at 625 pounds per square inch, round steel bars would need to be set but 24 diameters depth in the mortar to require the breaking limit of the bar in order to pull them from the cement.

On the other hand, experts say that as soon as sufficient force has been applied to elongate the metal rod appreciably, the rod has then become lessened in cross sectional area, and as concrete is not elastic to any measurable extent such decreased rod area means a breaking away from the adhesion and consequently a decreasing reinforcement to the concrete.

If, however, the bar is completely imbedded in the concrete and is gripped over each particle of its superficial area by a grasp equal to 625 pounds per square inch, it must take a very much greater stress to begin the process of elongation. Some of the most successful armored concrete builders ignore any additional mechanical means of uniting metal and concrete. Among the number may be named Monier, Hennebique, Weber and others. On the other hand, Ransome, Thacher, Roebling and others provide special means to cause a more perfect union between the two materials.

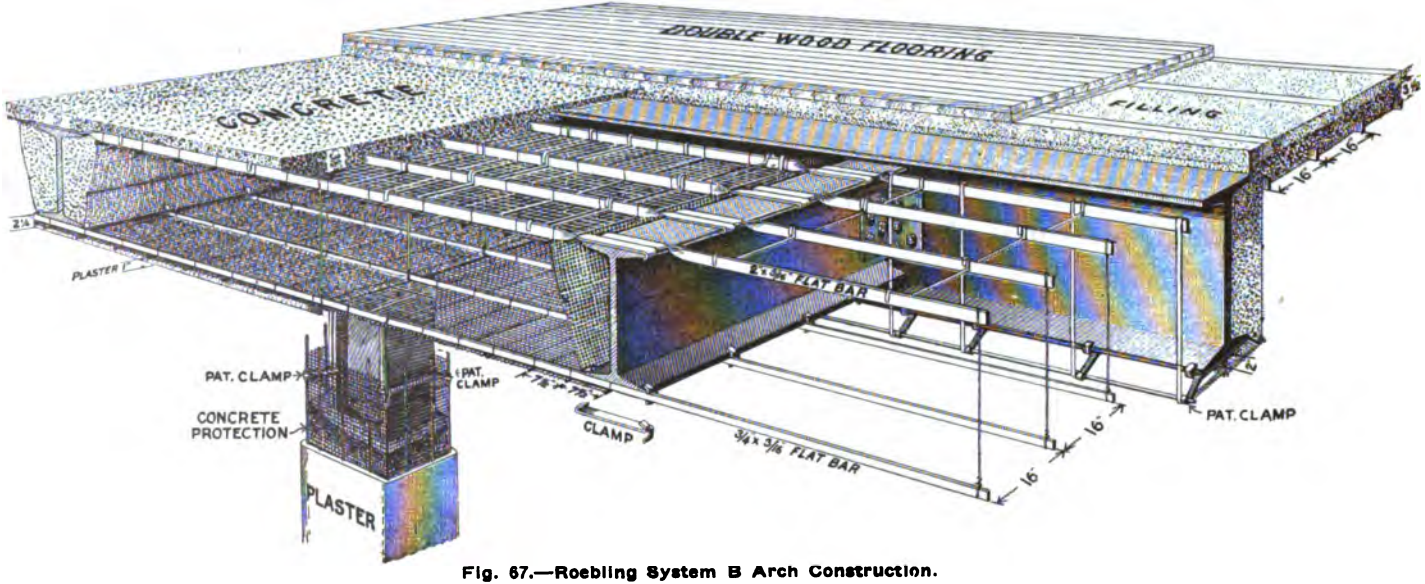


Fig. 67.—Roebling System B Arch Construction.

DESCRIPTION OF VARIOUS SYSTEMS OF REINFORCED CONCRETE.

But brief descriptions can be given here of the more important systems with their essential differences.

Monier System —In the words of Mr. E. Lee Heidenreich, C. E., the agent representing that system in this country, "The Monier construction consists of two materials, wrought iron or steel, and mortar, consisting of cement and sand, or cement, sand and broken stone. The iron or steel is either in the form of rods or wires, and are designated as carrying rods and distributing rods. The first ones being quite heavy are calculated to take most of the tensile strain of the construction; the distributing rods being lighter and serving the purpose merely to distribute evenly the load over the carrying rods. The two systems of rods are applied like a netting with meshes, varying according to the requirements of the construction, from say two inches to ten inches square. In most cases the distributing rods are placed at a distance apart equal to about twice that of the carrying rods."

The two systems of rods are wired together and this network of wires or rods is placed in the forms prepared for the concrete at about one-sixth of the thickness of the concrete plate from the side which is exposed to tension and held there by wedges until the concrete is thoroughly incorporated around the rods and fills the molds.

This system is applicable to any form of construction possible, the increase in the mesh and the size of the rod covering all the ranges of construction from a flower pot to a railway bridge. It is particularly adapted for the construction of the smaller sizes of sewer, irrigation and water supply pipes.

Roebling's System.—The Roebling system "A" consists of woven wire mesh stiffened by steel rods, which is sprung in between floor beams or girders in an arched form. Upon this arch, concrete is deposited and allowed to harden. For ceilings, a system of rods is attached to the lower flanges of the floor beams by patent clamps which offset the bars below the beams for one-half inch or more. Under these rods and securely fastened to them by wiring, is placed the Roebling woven wire lathing, reinforced with one-fourth inch stiffening rods. A coating of one inch of plaster composed of cement or "hard plaster" is troweled upon the under-side, thus producing their fire proof construction. This system is especially fitted for fire proofing floors, beams, columns, etc. Figure 66 shows it in detail. In their system "B," flat iron bars, set on edge, are clamped from beam to beam, both on top and bottom, and the wire meshing fastened to the bars. A 3½ inch layer of concrete is then put above the upper wiring and 1 inch of plaster below the lower wire mesh. In this method the floor beams are encased on all sides to prevent fire reaching them. Figure 67 shows this system.

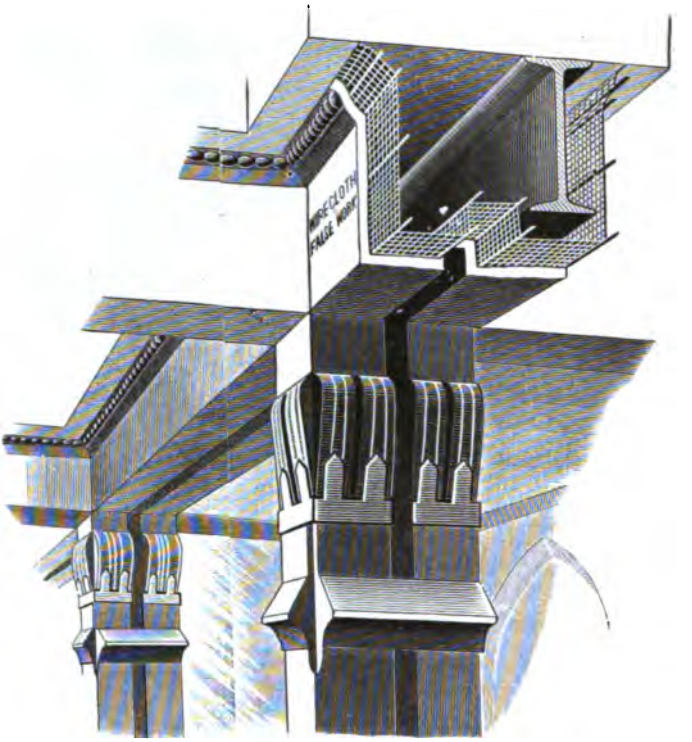


Fig. 68.—False Work for Giving Massive Effect in Plaster.

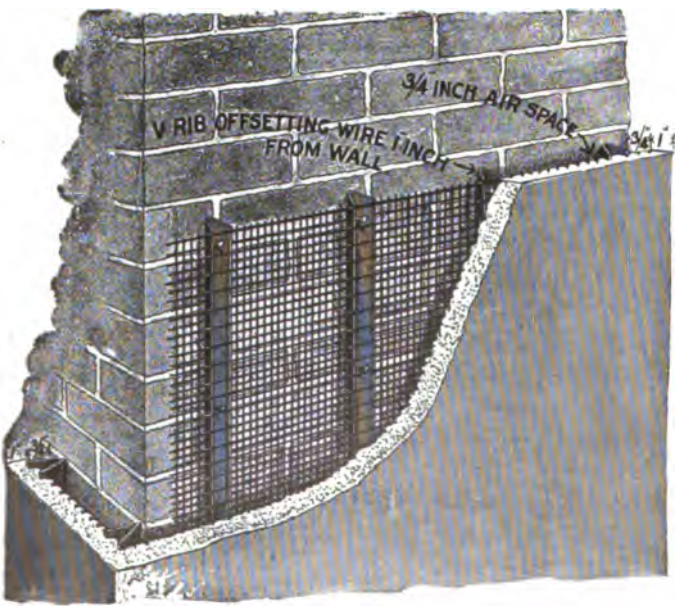


Fig. 69.—Exterior Wall Showing Metal Furring.

In protecting steel columns or girders, the wire lathing is furred out 2 inches or more from the member by specially designed metal clamps and bars, the space inside is then filled with cinder concrete before the outside is plastered.

The concrete used is 1 part Portland cement, 2½ of sand and 6 parts cinder. It is never rammed solidly, but allowed to set in porous form. It dries out quickly, is light, and the porosity prevents the fracturing of the concrete under sudden changes in temperature. Concrete under these conditions weighs about 80 pounds per cubic foot.

Strength of Roebling Arch.—To test the strength of the Roebling arch system, the New York Building Department in 1896 made a severe test upon a 4 foot arch. It was first subjected to a five hour fire test at temperatures ranging from 2,000° to 2,350° F. and then cooled by a stream of water from a fire engine. A section of the arch 4 feet long was then cut free from the remainder of the arch and the middle 2½ feet of this section was loaded with a load of 41,000 pounds, or a load of 2,556 pounds per square foot over the entire arch, which safely withstood the test. The heat of the fire test was sufficient to fuse the brick side walls and to cause the surface of the brick to run down the wall like molten metal. Figures 68 and 69 illustrate other methods of using the system.

Expanded Metal System.—Expanded metal consists in sheet steel slit in regular lines and then the strips forced apart forming diamond shaped meshes. Sheets of this metal are then laid over the girders with ends lapping and the concrete lightly tamped in around the metal. The metal is sometimes sprung in between beams as is done in the Roebling system. Expanded metal makes a very strong floor as is shown by a test made upon a floor slab for the Larkin Soap Co. of Buffalo, N. Y. A 4 foot 10 inch span of floor 3 inches thick and 13 feet 10 inches long was subjected to a uniformly distributed load of 2,333 pounds per square foot without indicating weakness. The load was then changed to a concentrated load 12 inches wide in the center of the panel extending for full panel length. The floor panel broke when the total load amounted to 4,855 pounds per square foot. Expanded metal is particularly adapted to thin partitions where the metal can be tacked to each side of metal or wooden studding and cement mortar plastered upon both sides forming a very durable solid wall of minimum thickness.

Melan System.—The Melan system consists of concrete reinforced with steel I-beams, bent to conform to the tension surface of the structure. In this country it has been principally used in bridges. The I-beams vary in size to suit the requirements of the span and load. They are set at intervals of two or three feet apart laterally, and the lower flange is kept about three or four inches from the bottom face of the arch. As the concrete varies in depth from the crown to the haunch of

the arch, it follows, that a single I-beam gives no reinforcement to the top surface of the concrete at the haunch. It was to avoid this defect and

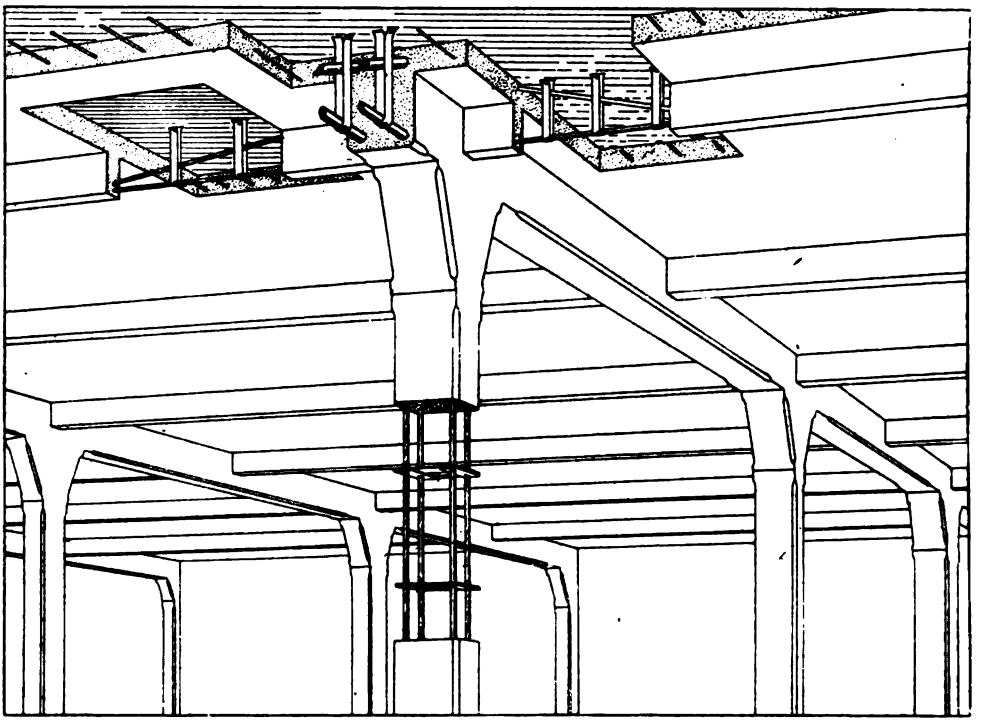


Fig. 70.—Floor and Post Construction, Hennebique System.

to secure a simpler, more conveniently obtained form of steel that Thacher introduced his system described below.

Thacher System.—The Thacher system of reinforced concrete is particularly designed for bridge construction. It consists of pairs of flat iron or steel bars laid near the upper and lower surfaces of the arch, spliced and riveted so as to be continuous from one abutment or pier to the next. These two members are tied together with vertical iron rods spaced two or three feet apart. Large headed rivets are set in the bars at short intervals to give a better bond with the concrete. The pairs of bars are spaced about three feet apart laterally and not connected. These bars act as the flanges of a beam of which the web consists of the body of concrete. The advantages of this system are: The simplicity of the metal forms, the convenience in obtaining, shipping and handling, and the ability to place the metal nearest to the maximum tensile straining points. It gives greater moment of inertia and consequently greater strength for the same amount of metal than does the original system from which it sprang; namely, the Melan I-beam system. The special

Thacher rolled bar, (a later design) does not have the first two advantages named. Illustrations of Thacher's original method of reinforcement will be given later under the head of bridges.

Hennebique System.—The Hennebique system gives the effect of a trussed concrete beam by the use of two sets of round iron bars. One set is straight and laid near the lower edge of the beam, the other is bent upward at the ends, approaching the upper part of the beam. Besides these, vertical U-irons, or stirrups, are used to assist in resisting both shear and bending. Application of this system to columns and other forms of construction is quite as simple. In the column four or more round iron rods are used, bound together at frequent intervals with iron plates through which they pass, or they are bound together by being heavily wired. These rods give the tensile resistance required while the concrete gives the compressive resistance and rigidity to the structure. The Hennebique system has been used in every form of construction in which armored concrete can be used—tanks, stairways, floors, walls, bridges, piles, etc. Figures 70 and 71 show its detail for floors and beams.

Contrary, also, to usual practice, Hennebique prefers the steel or iron to be "covered with rust to facilitate the foundation of an extra hard coat of ferro-concrete, which prevents the penetration of moisture and air to the metal."

Ransome System.—The Ransome construction "consists in the use of iron bars, cold twisted, so as to form a continuous bond with the concrete, in which they are permanently imbedded."

"The basis of the system is the method of introducing iron with concrete in such a manner as to give to the concrete beam or girder the power to resist tensile stresses, as if the beam were of a fibrous or homogeneous material, like iron or wood. In such a construction it is essential: *First,* that the iron and the concrete be so united as to enable each to act immediately with the other in resisting stresses. *Second,* that the bond between the two should be continuous and equal from one end of the beam to the other. *Third,* that the elastic limit of elongation of the two should be made as nearly equal as possible."

Ransome claims for his system of cold twisted bars, increased elastic limit, decreased elongation under strain, the detection of all serious imperfections in the iron before it is put into use, and a more secure union of the metal and concrete. He does not attempt the trussing effect, but allows the concrete to form its own truss, depending upon the iron to supply the tension member. It costs about one dollar per ton to twist the iron so that if all is gained that is claimed, the twisting certainly pays. In floor or surface construction, auxiliary bars are used running at right angles to the main system of bars.

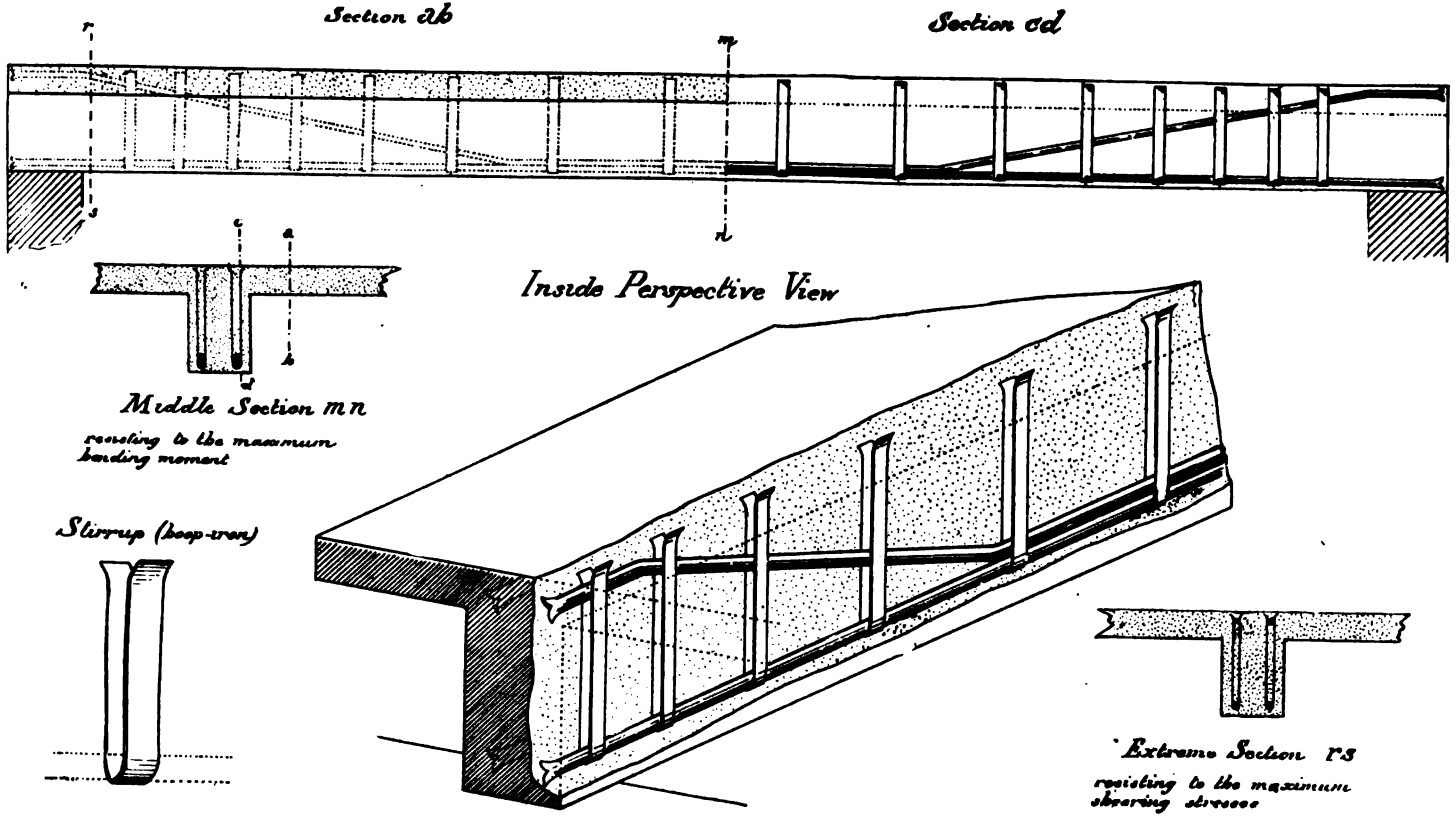


Fig. 71.—Details of Construction, Hennebique System.

Weber System.—In the Weber system steel T bars are used for reinforcing the concrete, the advantage being that the T form gives a much greater surface contact for union with the concrete, than do round or square bars having the same cross-section. The T shape also resists a much greater bending force for equal amounts of metal. This being one of the standard shapes is readily obtained at reasonable prices. Longitudinal and lateral bars are easily clamped together, back to back, by specially designed clamps which work very simply so that the reinforcing skeleton is quickly put in place. Figure 72 shows the details of this system.

Kahn's System.—This is one of the later developed systems, and seems to have some excellent features to commend it to engineers. In the first place it is a form which can be easily rolled and easily cut and pressed into the shape desired. In the second place it seems to offer a reasonable solution of furnishing the tension member at every position where it is most needed. It amounts to the same reinforcement furnished by the Hennebique system, and does it with a much simpler piece of metal to place in position. Its form readily fits it for a great variety of structural purposes. It would seem to be especially adapted for floors, beams and walls. Figure 73 shows the shape of the metal member.

Columbian System.—The Columbian system is another method of using bars and strives by the shape of the bar used to gain in rigidity and in binding union with the concrete. The bar is ribbed, having a central web from which three to six ribs running longitudinally of the bar set out at right angles on each side. As it is an unusual form, it can only be obtained at the few rolling mills which may install the necessary rolls. Being an unusual form it will probably cost more than the simpler and customary forms. The claims made for it are: The greater surface presented for adhesion of concrete, the rigidity of the metal piece itself, and the additional rigidity given when supported by concrete firmly imbedded between the ribs or flanges. Figure 74 shows a section of the metal.

Cumming's System.—This system employes round iron rods in place of the Kahn system of flat ribbed bars. These rods are bent into sets of long, slim parallelograms. Each parallelogram is sufficiently narrower than the one preceding it to lay within it and is considerably shorter. A short portion of the ends of each parallelogram is then bent up to make an angle with the horizontal of about 45 degrees. This nest of bent parallelograms is then laid into the form with its lower edges about two inches from the lower surface of the beam. The concrete is then tamped into place. The result accomplished is the same as with the Kahn reinforcement, but the accomplishment is not so simply and easily attained. Figure 75 illustrates the metal forms.

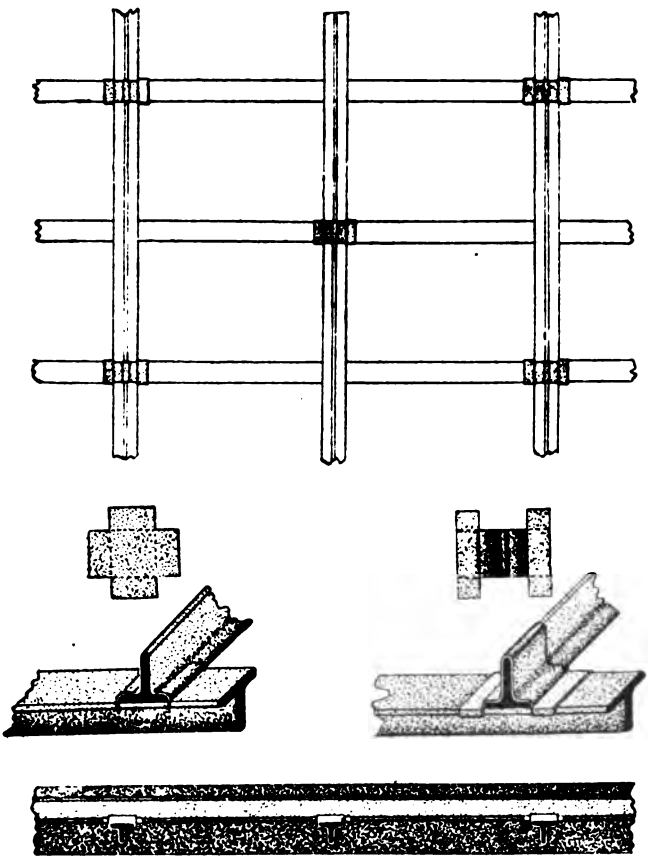


Fig. 72.—Details of Construction, Weber System.

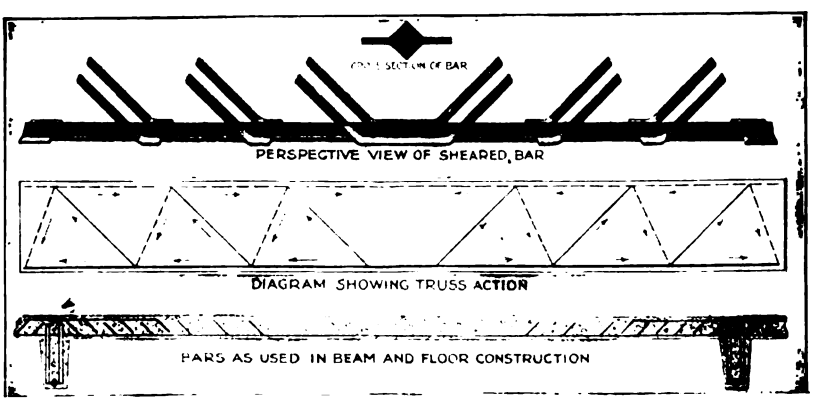


Fig. 73.—The Kahn System of Metal Reinforcement.

DeMan's System.—DeMan uses a flat steel bar with quarter twists put into the bar, alternately to the right and left, at intervals of two to four inches, according to the size and depth of bar. These bars are shaped so as to hook over the I-beams and are straight longitudinally except for the twists. This system is designed principally for floors. A specially designed concrete floor block is made which is cast at central manufacturing plants and shipped to the building, ready to slip into place between the floor girders. This block is as deep or deeper than the I-beam and rests upon the lower flange. The DeMan steel bars being special shapes are not as readily obtained as standard forms and consequently are objectionable for that reason.

Luten's System.—Luten's system pertains more especially to bridges and culverts and is particularly an application of any system of reinforced concrete, to a certain method of building rigid structures. Instead of allowing the thrust of the arches to be taken up by abutments, and embankments, a steel concrete tie is inserted from the base ends of the arches, making a monolithic complete structure, capable of sustaining all the varying stresses within itself. The advantages secured are: Prevention from arch rupture due to settlement, the possibility of flatter arches, a more rigid resistance to action of floods and possibly a slightly less amount of material necessary in construction. Figures 76 and 77 show a section and view of bridges illustrating this method.

It will be seen from the preceding discussion and descriptions that reinforced concrete gains its marked pre-eminence over plain concrete in such structures as bridges, girders, beams, floors, roofs, thin walls, chimneys, piles, etc., structures where great tensile strains enter into portions of the building. Again, in localities where both stone and gravel are scarce, reinforced concrete, because of the reduced amount of material required, is very economical. In describing the uses of reinforced concrete, but brief attention will be given to such structures as are commonly built with plain concrete, except, perhaps, to occasionally compare the results obtained by the two methods. The various methods of building beams and girders have been so well illustrated in describing the various systems of reinforcing, that they will not again be mentioned.

STEEL CONCRETE FOOTINGS.

The soil in Chicago is especially noted for its instability. This condition requires the highest engineerng skill to be used in designing rigid, firm foundations for the "skyscrapers." The old form for foundations was of stone or immense blocks of concrete, taking up the room which should be given to basements and adding so much extra weight to the total load which the foundation soil had to sustain. To obviate these objections, the first combination of steel with concrete for heavy founda-

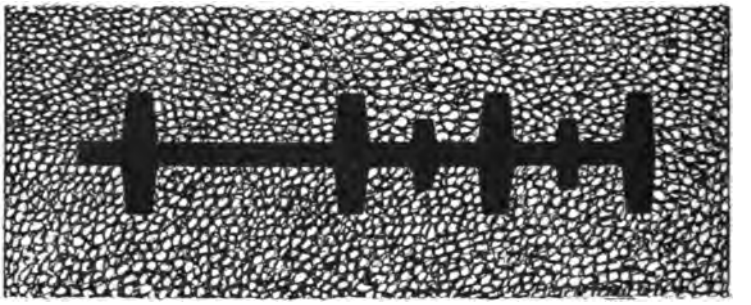


Fig. 74.—The Columbian System of Metal Reinforcement.

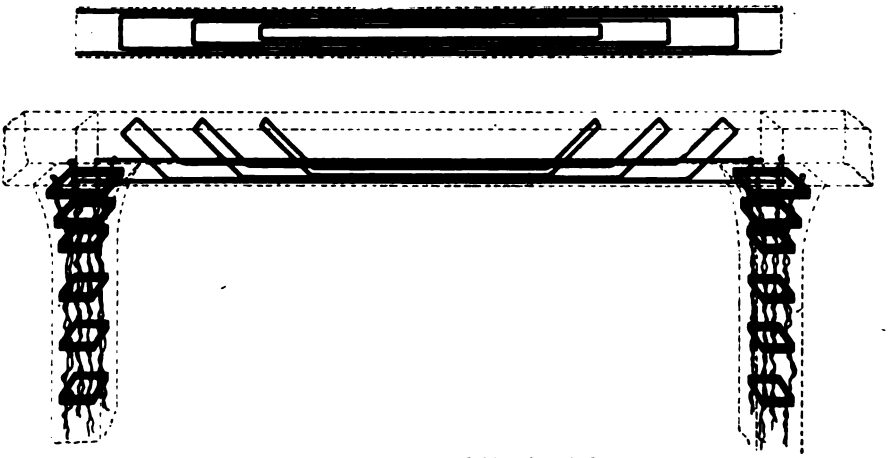


Fig. 75.—Cummings System of Metal Reinforcement.

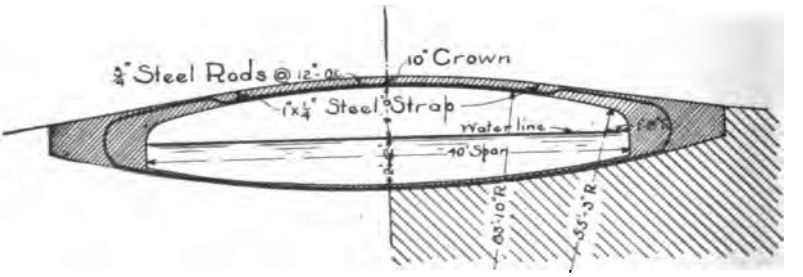


Fig. 76.—Section of a Bridge With Forty-Foot Span, Lafayette, Ind.
The Bed of the Stream is Paved With Concrete.

tions was designed. These foundations consisted of beds of concrete with grillages of steel rails or I-beams bedded in concrete, on top of them. Such foundations have long been successfully used there under the most trying conditions.

Fig. 77.—A Flat Elliptical Arch Bridge.

In order to compare the two forms, figures 78 and 79 are taken from an article by Mr. T. Corydon Purdy, published in Engineering News. Both foundations begin with a bed of concrete 18 inches thick and 16½ feet square. Both were designed to carry a load of 800,000 pounds. The height of the steel-concrete foundation is 18 inches over the base, while the stone foundation is 7 feet. The weight of the steel concrete foundation is 103,000 pounds, and that of the stone foundation is 261,000 pounds. The reduction in weight is more than sufficient to allow an additional story to the building without extending the footings. The decreased depth of footings allows space for a basement. The steel concrete foundation can be erected in much shorter time. It is susceptible of development into cantilever form and therefore becomes particularly useful for sustaining separate walls along party lines. Thus steel concrete foundations save in basement space, in weight upon foundation soil, in time of construction, and in first cost.

The I-beam grillage, however, used a great deal of steel which it has since been discovered could be saved by using much smaller bars or rods imbedded in the concrete in grillage form. Figures 80 and 81 show another comparison which the St. Louis Expanded Metal Company make, and in which they claim that the first cost of construction saved by using bars is nearly as great as the saving in space.

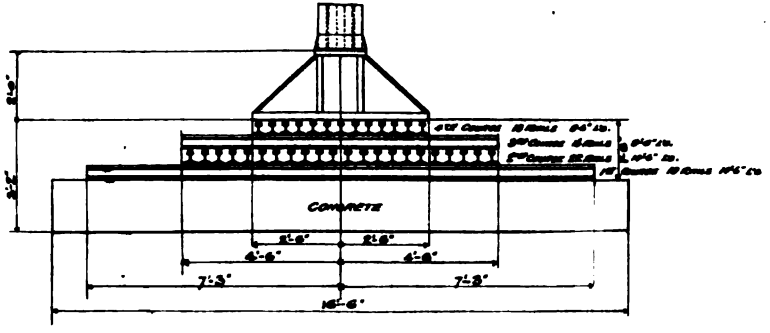


Fig. 78.—Steel Concrete Foundation.

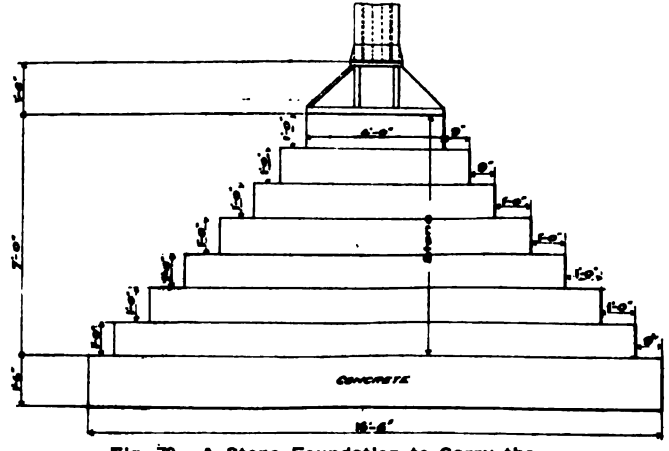


Fig. 79.—A Stone Foundation to Carry the Same Load as Provided for in Fig. 78.

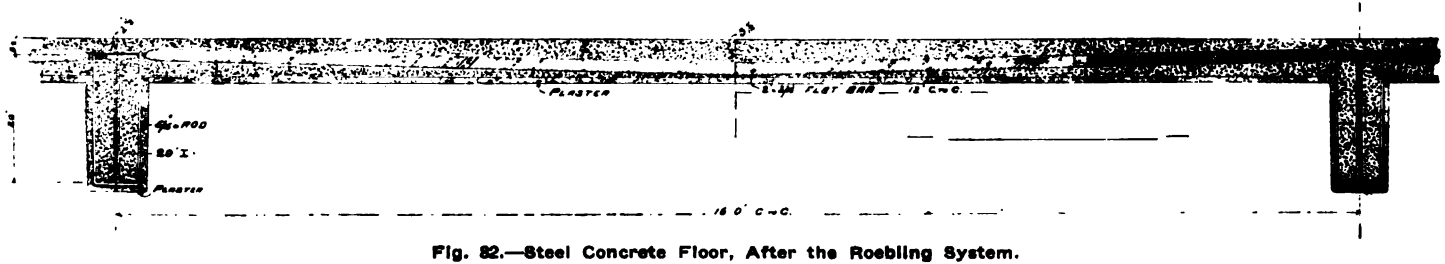


Fig. 82.—Steel Concrete Floor, After the Roebling System.

COST OF PLAIN CONCRETE FOOTINGS.

Excavation, 11½ cubic yards, at $ .50	$ 5.75
Concrete, 205 cu. ft., at $ .20	41.00
Total cost	$46.75

COST OF CORRUGATED BAR FOOTINGS.

Excavation, 7½ cu. yds., at $ .50	$ 3.75
Concrete, 102 cu. ft., at $ .20	20.40
Corrugated bars, 382 lbs., at $ .03	11.46
Extra Column length, 85 lbs., at $ .03½	2.98
Total cost	$38.59

A saving of nearly 17½ per cent. in cost. The percentage of saving increases rapidly as the size of the footings increase.

WALLS.

To have partition walls that are solid, fire proof, economical of space, and poor conductors of sound is one of the requisites of a modern office building. It is useless expense to construct any but ideal walls when so many good structural forms are available.

While visiting the Pacific Coast Borax Company's works, at Bayonne, N. J., in the summer of 1902, the writer was shown the partition walls which withstood the destructive fire that occurred in that building a few months before. The walls were of Ransome steel concrete three inches thick. To illustrate the strength of the wall the superintendent picked up a large wooden maul and swinging it at full arm's length, gave the wall repeated blows with all the force he could command. The wall vibrated slightly, but no other effect was produced.

FLOORS.

In all large cities, architects, owners, and building departments are striving to attain perfection in fire proof buildings. Attention is especially being directed toward construction that will confine fires to the rooms in which they begin. Fire proof walls should be accompanied with fire proof floors, stairways and elevator shafts. The old method of arching brick or massive concrete between steel I-beams is too cumbersome. Such floors are very heavy, adding to the weight which must be sustained by the floor beams, columns and foundations. They are not entirely satisfactory when it comes to severe fire tests, for the under sides of the steel I-beams are exposed to the heat of the fire and are soon warped out of shape, destroying the floor and allowing the fire to sweep upward through the entire building.

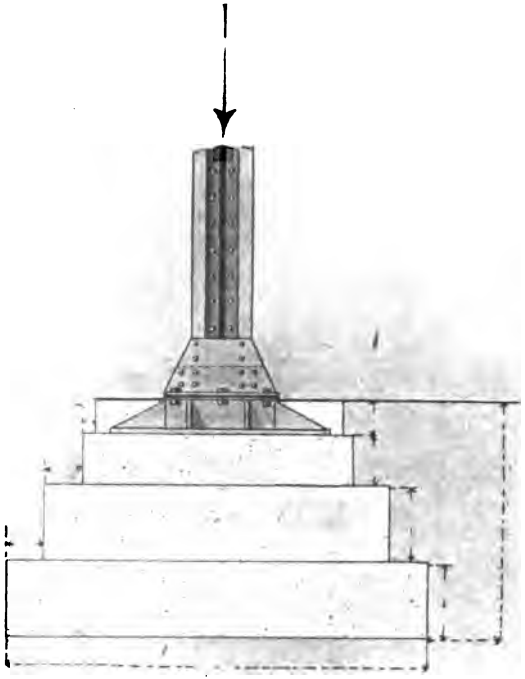


Fig. 80.—Plain Concrete Foundation.

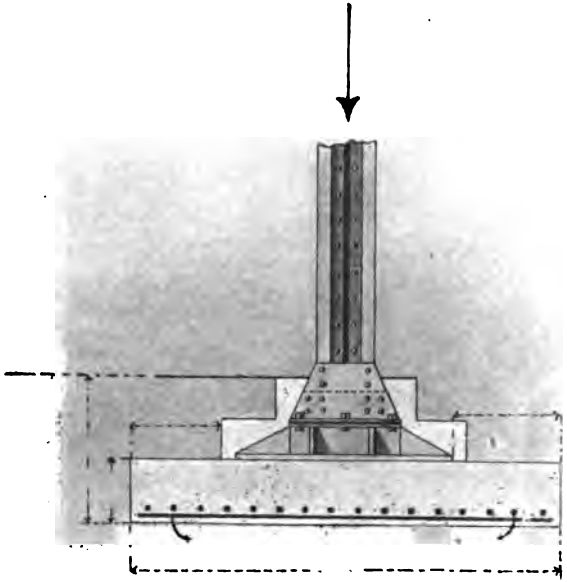


Fig. 81.—Reinforced Concrete Foundation to Carry the Same Load as Fig. 80.

Steel concrete floors and beams were designed to meet tnis objection. Contractors have become bolder and bolder as experience and science have taught them the strength of this combination, until it is not unusual now to find four inch floors of steel concrete spanning 18 by 22 foot bays. These floors are made of excellent concrete having iron rods or bars imbedded in the lower third of the mass and supported upon steel concrete beams or girders. Figure 82 shows the section of such a floor.

"This type of flooring is similar in every way to the other System B floors (Roebling's) except that the flat steel bars are bent or crooked downward 2 inches or more at the center of the span and imbedded in that position in the concrete. This type is particularly well adapted for floors of light capacity and where special conditions make it necessary to economize as much as possible in the structural steel. Where the distance between the steel members or supports is more than 9 or 10 feet, this form of flooring will be found more economical than any other. It may be employed to span directly from girder to girder, dispensing with the customary intermediate beams. Type 5 has been installed successfully in spans up to 22 feet. Under ordinary conditions, however, considering both the steel work and fire-proofing the most economical results will be obtained when the girders are spaced 14 to 16 feet apart. The weight of the concrete and imbedded steel bars as shown in the illustration is 43 pounds per square foot; plaster (two coats), 7 pounds."

English Practice in Floor Construction.—Mr. Frank Caws, who has had thirty-two years experience, gives the following rules for concrete floor construction, in an article written for the Journal of the Royal Institute of British Architects.

1. Obtain old cement.
2. Use good broken brick aggregate and not sand, body concrete to be 1 part cement and 4 parts brick and the surface to be 1 part cement and 3 parts crushed granite.
3. Use as a precaution, "Sheep-wire netting" as a base and steel bars of 1½ pounds per foot in weight spaced 3 feet apart.
4. Consider a slab 10 feet square by 4 inches thick capable of bearing 900 pounds per foot in weight including its own weight and reckon for every slab, more or less than 900 pounds per foot directly in proportion to the square of the thickness and inversely as the cube of its span. When the span is rectangular the minimum span is taken.
5. Avoid casting slabs in frosty weather.
6. Cast large areas at once, leave no partially cast slab over night.
7. Insist on strong centering—leave it up at least five weeks.

STAIRWAYS.

If stairways and elevator shafts are of wood then fire will be carried from floor to floor, so that these, too, are now constructed of steel con-

crete. Not only in business houses but also in the finest residences concrete stairways are used.

George W. Vanderbilt's fine residence on Fifth Avenue, in New York City, is just being erected with a fine double spiral stairway. These spiral stairways curving in opposite directions intersect midway between floors, then swinging apart again continue to curve to the upper floor. They are self supporting, without beams, girders or columns. They are of exceptionally light construction, the concrete spiral, being 64 inches wide and 4 inches thick, with side panels or vertical edges 4 inches thick and 14 inches high. Ransome twisted bars ¼ inch square are used,

Fig. 83.—Steel Skeleton for Spiral Stairway, Geo. W. Vanderbilt's residence, New York.

mainly, for reinforcing material. The concrete used was mixed in the proportions of 1 part cement, 1½ sand 3 parts of ¾ inch trap rock. Two weeks after the erection, the stairway bed was loaded with 3,300 pounds and showed no deflection. For a second test a 380 pound weight was dropped 11 feet upon the center of the floor bed without any perceptible effect. The wooden stair treads are to go upon this spiral sweep of concrete. The reinforcing rods were carefully bent to fit every curve and were in continuous lengths from the first floor to the intersection of the spirals, thence other rods from that point extend to and are bolted into one of the steel floor beams above.

In designing the house, it was found that all steel or other construction would have either required outside support or have been too heavy in appearance. This was the reason for adopting the light, graceful, steel-concrete work.

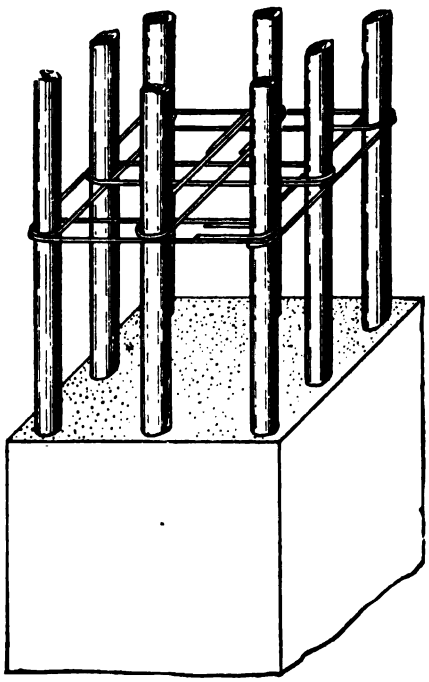


Fig. 84.—Section of Steel Concrete Column, Hennebique System.

COLUMNS AND PILLARS.

So many disastrous fires have occured where iron columns have been used that architects have been seeking continuously for a remedy or a new material to replace the old.

Originally, fire proofing material was erected around the iron columns and this method is now much used. Both terra cotta forms and expanded metal, or wire lath with concrete are used for this purpose. Quite

a controversy has been aroused between the advocates of the two materials, in which the concrete people seem now to have slightly the advantage. But going beyond this use of a concrete veneer, the more advanced have omitted the large iron members and have substituted a concrete column with a few round or square steel bars placed vertically in it and have secured a column that no fire can warp or affect in any way.

Figure 84 shows the latter construction.

In the Christian Science Temple near Broad Street and Grant Avenue in Columbus, Ohio, the architect has saved the expense of stone and stone cutter's wages by making the porch pillars of concrete. Carpenters have built forms out of lumber. These were filled with concrete, and now symmetrical and inexpensive masonry pillars adorn the front of that concrete temple. The walls themselves are constructed of concrete blocks made upon the ground.

Figure 85 shows the unfinished front of this building and figure 86 is a more detailed view of the foot of the columns.

Fig. 85.—Front View of Christian Science Temple, Columbus, Ohio.

ROOFS.

Nassau County Court House.—A description of the Nassau County Court House, at Mineola, Long Island, will probably illustrate the use of steel concrete in many of its forms as well as anything that has been done in that line. This county had experienced the loss of its records by fire, as many counties have throughout the United States, so that the

Fig. 86.—Detail of Pillars.

Fig. 87.—Court House at Mineola, Long Island, N. Y.

county officials decided to erect a fireproof building. This building was erected, in 1901 and 1902, entirely of steel concrete. It is a two story building erected in the form of a ⊥. The main building is 176 by 37 feet and the central stem is 60 by 52 feet in area. The whole is surmounted with a circular dome 25 feet in diameter and 62 feet high. The foundations, walls, columns, floors, roof, dome and ceilings are all of steel-concrete, monolithic in construction. The body and trimmings of the exterior walls are beautifully contrasted by constructing the body of concrete composed of crushed trap rock while the trimmings are of crushed marble concrete. The porch columns, interior columns, cornices, etc., are of the marble concrete. The interior walls are covered with a hard white plaster placed directly upon the concrete surface. The exterior walls, the concrete fences and gateways are bush hammered, giving a fine natural stone appearance. The floors in the building are of concrete in the proportion of 1 part cement, 2 sand and 3 parts crushed stone. They are 2½ inches thick, in panels 20 to 30 inches wide and 12 to 28 feet in length. The floors in the main portions of the building have 2

Fig. 88.—Rotunda in Mineola Court House.

inch top slabs and 1½ inch ceiling slabs resting on concrete beams spaced from 17 to 24 inches apart. No steel is used in the floor and ceiling slabs, but steel bars are used in the top and bottom of the beams.

In the rotunda there is a circular light-well 14.5 feet in diameter, around which the upper floors are supported by a circular concrete girder 10¾ inches wide and 20⅜ inches deep, having a single ¾ inch steel bar imbedded in the concrete at the top and bottom. From this girder radiate other concrete girders to the side walls, thus giving the circular girder support. The floor in the rotunda is 3½ inches thick made in 8 by 10 foot panels, reinforced with ¼ inch bars spaced three inches apart and bedded in the lower portion of the concrete about ¾ inch from the lower face.

The exterior walls are hollow, with occasional ribs connecting the outer and inner wall slabs. The hollow spaces contain heating and vent ducts. The outer wall slab is 3 inches thick and the inner 2 inches, with 15 inch air spaces between. The concrete used was made of 1 part cement, 2 parts sand and 4 parts crushed stone.

The roof is like the floors, but is lighter and has no ceiling slab beneath the concrete rafters, except over the large court room where the vaulted ceiling with a clear span of 49 feet has a 2 inch shell connected with the 2 inch roof shell by 5 inch transverse ribs spaced 3 feet apart in the clear. A shrinkage joint is provided at the ridge to care for expansion and contraction.

The dome roof has a solid shell 3 inches thick without ribs and reinforced by ¼ inch steel bars, both horizontally and radially, the horizontal bars being 12 inches apart and the radial bars 12 inches apart at the base of the dome. The rods are ¾ inch from the outside of the shell at the base of the dome and cross over at about three-fifths of the height of the dome to ¾ inch from the inside of the shell. Plaster forms were used for the outer part of the dome and for the decorative features, while wooden forms were used for the inner surface of the dome and the work in general.

The building contains 70.000 cubic feet of concrete and 80,000 pounds of steel, and cost about $106,000.00. The specifications required a sectional area of one square inch of steel and four square inches of concrete for each 2,000 pounds of tensile and compressive strain respectively.

Unscreened broken stone, having a maximum diameter of ¾ inch, with Atlas Portland cement was used in the concrete. Figures 87 and 88 illustrate this work.

To illustrate the Hennebique system of concrete floors and roofs, a section of Mr. W. C. Sheldon's five story residence on Fortieth street, New York, is presented in figure 89. The extreme lightness of the construction is clearly shown.

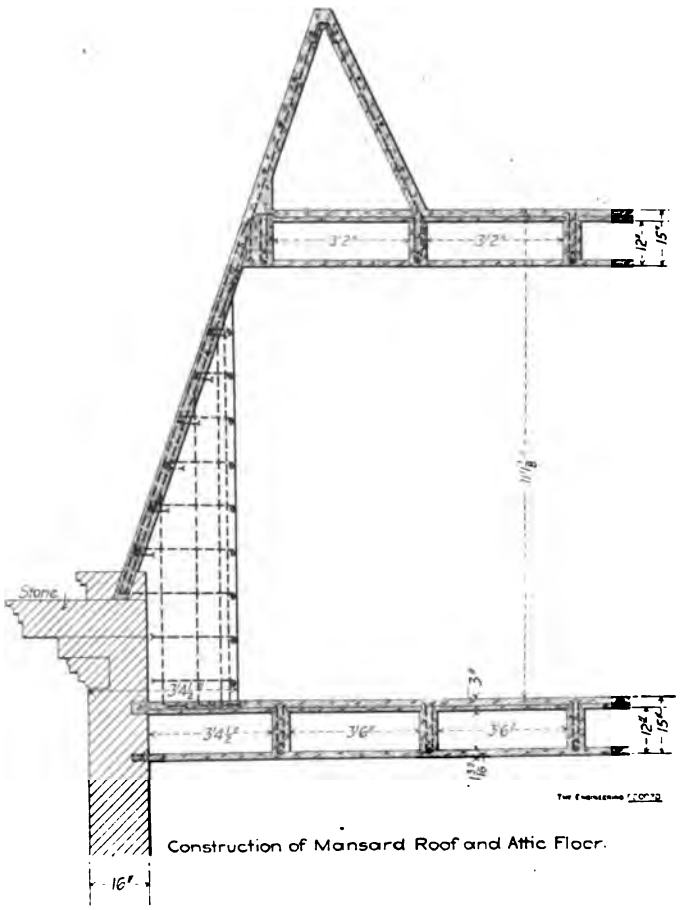


Fig. 89.—Mansard Roof and Attic Floor, W. C. Sheldon's Residence, New York.

CHIMNEYS.

Figure 90 illustrates the tallest concrete chimney in the United States. It was erected in 1902 for the Pacific Electric Railway Company's power house in Los Angeles, Cal. It is built of steel concrete and is 180 feet high, 18 feet in diameter at the base and 15 feet in diameter above the shoulder with an interior diameter of 11 feet. It is built of two shells; the outer shell is 9 inches thick for the bottom third of its height, 6 inches thick for the middle third and 5 inches thick for the top third; and the inner shell, which is to provide for the expansion and contraction due to the heated gases from the boilers, has a bottom thickness of 5 inches and a top thickness of 4 inches. It is designed to give draught capacity for a 6,000 horse-power plant. The two shells have no connection with each other. The material was mixed by machinery upon the ground and hoisted through the interior to the scaffold which was arranged to be extended readily after each day's work. An exterior scaffolding was swung just below the working forms to catch

any one who might accidentally fall. The proportions of concrete used in the inner shell were of 1 part cement, 2 sand and 4 stone; in the outer shell, 1 part cement, 2 sand and 6 stone.

There are four or five other large concrete chimneys in this country: One at South Bend, Ind., one for the Algonquin Hotel in Dayton, Ohio, and two in New Jersey, one of which, at the Pacific Coast Borax Company's plant, is 150 feet high and 7 feet inside diameter; the other, at the Central Lard Company's plant, is 108 feet high and 8 feet inside diameter.

TANKS, SILOS AND ELEVATORS.

Steel concrete has been used for gas-holder tanks, coal bins, lime bins, cement storage bins, water towers, grain elevators, silos, etc. As

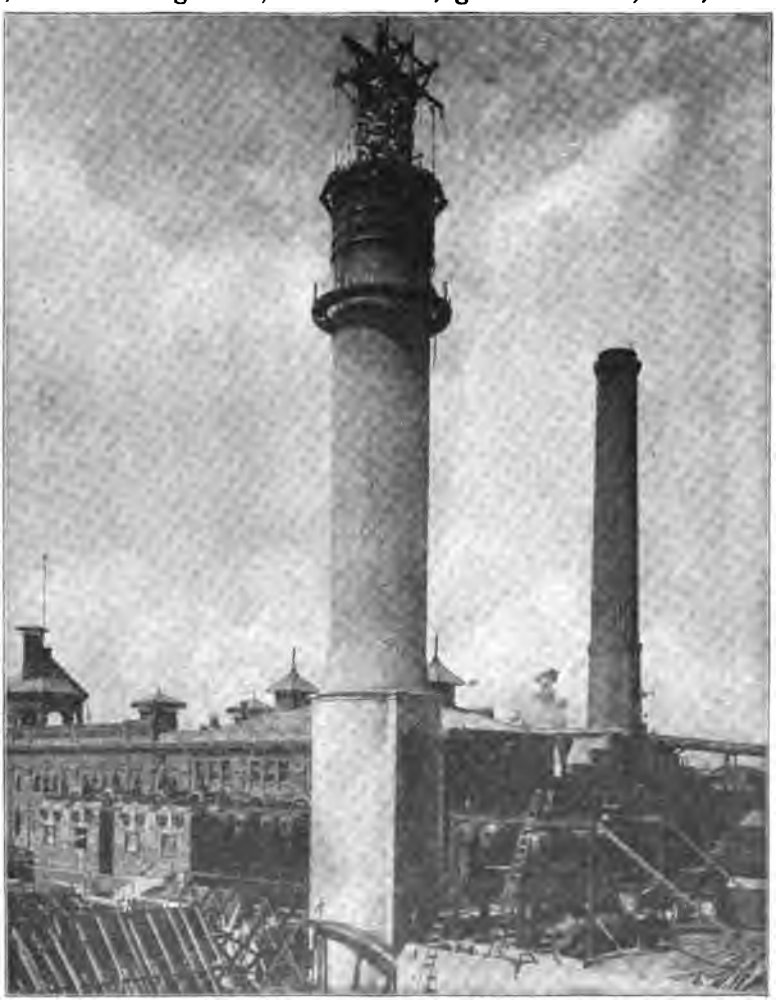


Fig. 90.—The Tallest Concrete Chimney in the United States (in Process of Construction), the Pacific Electric Railway, Los Angeles, Cal.

these all have similar form and require the same character of construction, space will only be taken to describe a couple of forms.

Illinois Steel Company's Cement Bins.—In 1902, the Illinois Steel Company erected four steel concrete cement storage bins at South Chicago. They are 25 feet in diameter and 53½ feet high, set upon the four corners of a square. They are mounted upon columns, 15 feet above the ground and the tanks being connected together, the space between them is also used for storage purposes. The walls of the tanks are 7 inches thick at the bottom and 5 inches thick at the top. The reinforcing

Fig. 91.—Concrete Bins for Storing Cement, Illinois Steel Company, South Chicago, Ill.

metal used was a 1 by 4 inch No. 9 wire mesh attached to and stiffened by circumferential rods spaced 4 inches apart vertically and varying in size

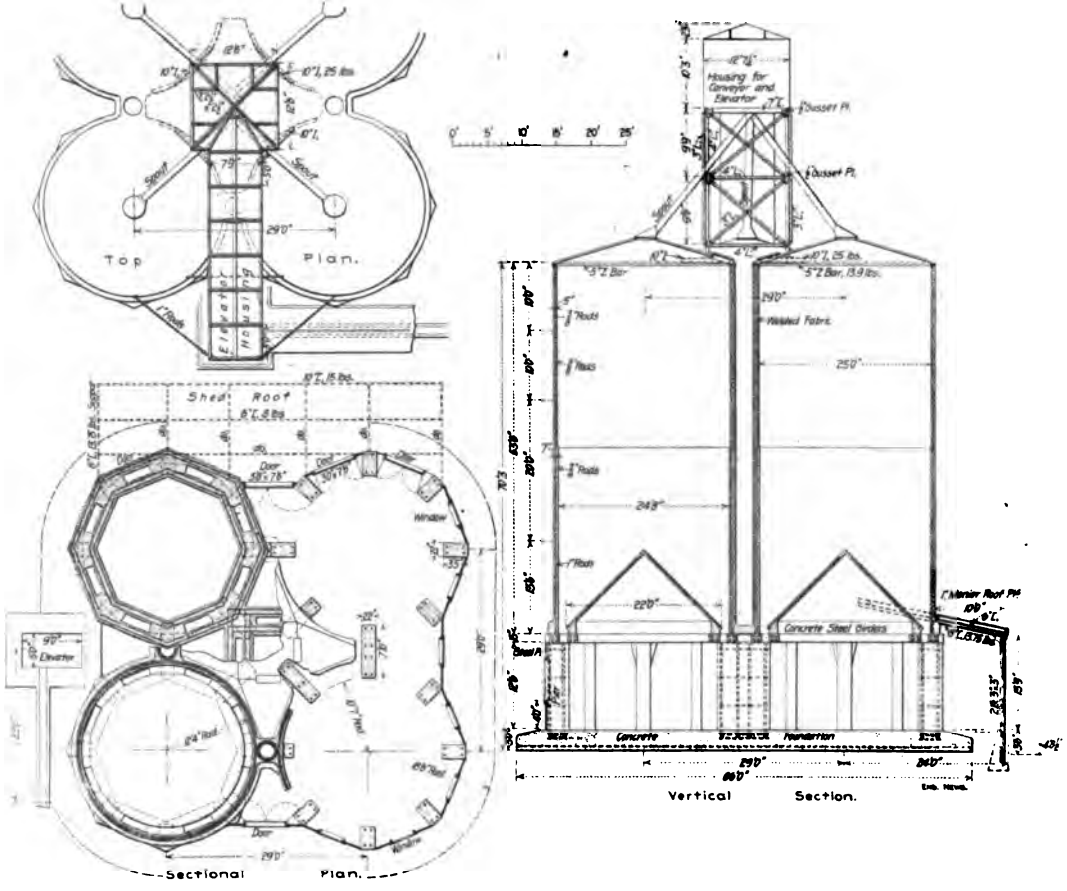


Fig. 92.—Plans of Cement Storage Bins, Illinois Steel Company.

from 1 inch in diameter for the bottom rods to ⅜ inch in diameter for those used at the top. The roof is 2 inches thick. The supporting columns are steel railroad rails imbedded in concrete and resting upon a foundation of concrete 3 feet thick having wire mesh imbedded in the bottom portion. The bottom of the tanks have a conical shape with the apex of the cone up and are 4 inches thick. The concrete in the foundation was composed of 1 part cement, 3 sand and 4 parts stone, and the concrete for the tank shells was 1 part cement and 3½ parts sand. The work was carried on day and night in order to prevent the necessity of placing fresh concrete upon set concrete faces. The capacity of the tanks is 25,000 barrels of cement.

Fig. 93.—Water Tower, Revere, Mass.

Water Tower, Boston Harbor.—At Fort Revere, at the entrance to Boston harbor, the first steel concrete water tower built in this country has just been completed, although several have been built in Europe during the past few years. It consists of a large steel concrete tower 93 feet high with foundations 5 feet deep, enclosing and supporting a steel concrete water tank 50 feet high and 20 feet in diameter. The wall of the tank is 3 inches thick at the top and 6 inches thick at the bottom, coated inside with one inch of 1 to 1 cement mortar, and on the outside with ¼ inch of the same. The bottom of the tank is 4 inches thick. The wall is reinforced by two systems of vertical 5-16 inch rods spaced 2 inches apart transversely and 16 inches apart circumferentially, also by two sets of horizontal hoops of ½ inch bars spaced 1¾ inches apart vertically at the bottom and gradually increasing the spacing to 3¾ inches toward the top, the upper portion being ⅜ inch bars space 3 to 3¾ inches apart.

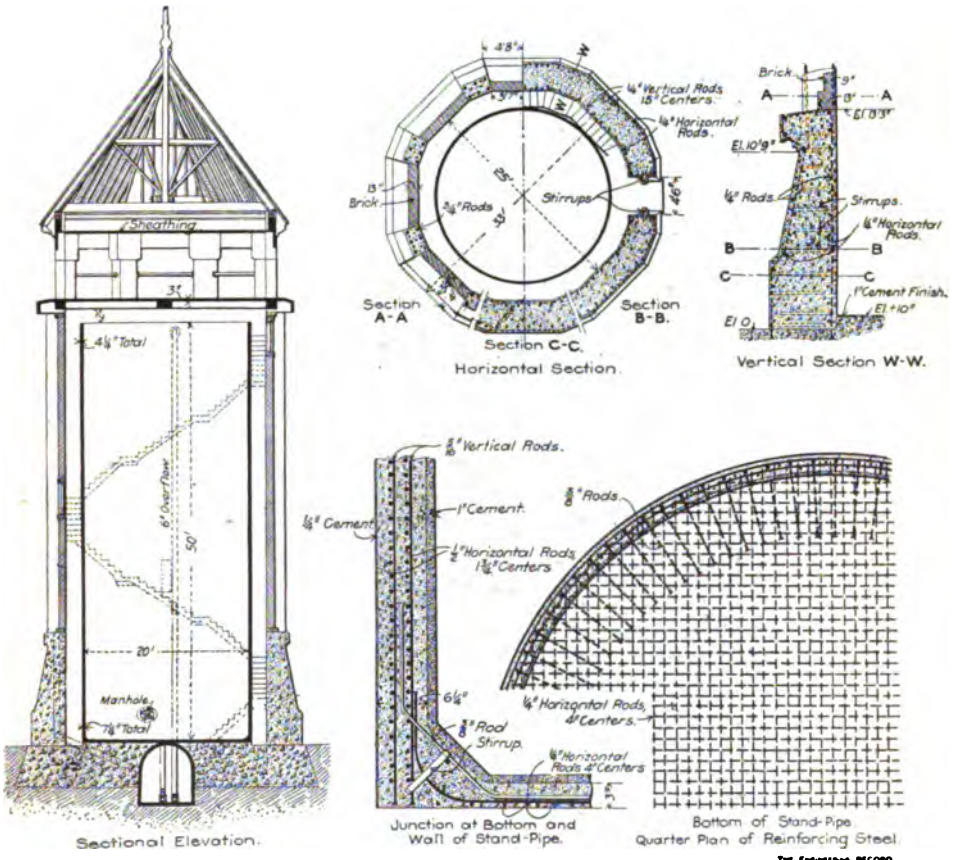


Fig. 94.—Details of Water Tower, Revere, Mass.

The concrete was mixed in the following proportions: For the foundation 1 part cement, 3 parts sand and 6 stone. For the tower 1 part cement, 2 parts sand and 5 stone. For the water tank 1 part cement, 2 parts sand and 4 stone.

Figures 91 and 92 show the plans and a photograph of the Illinois Steel Company's cement bins. Figures 93 and 94 show the plans and a photograph of the Revere water tower. Figures 95 and 96 illustrate the use of concrete for water tanks and silos.

Fig. 95.—Water Tank for Stock at Clarke Lake, Michigan.

BRIDGES AND CULVERTS.

The First Concrete Bridge.—The first concrete bridge constructed in the United States was built over Pennypack Creek on Pine Road, Philadelphia. It was designed by Mr. C. A. Frik, superintendent of bridges in Philadelphia, and was built in 1893.*

The bridge consists of two spans each 25 feet 4¾ inches long, with a rise of 6 feet 6 inches. It is 34 feet wide and carries a 26 foot macadam road. The arches are 2 feet, 3 inches deep at the crown. The spandrel walls and the faces of the arches are molded to represent Ashlar masonry, and then pebble dashed for a surface finish. Imported Portland cement

*Engineering News, Sept. 7, 1893.

Fig. 96.—Cement Silo on Thomas Hodgins Farm, London, Ont.

was used in the work. To strengthen the work, 1½ inch wire mesh was placed about 2 feet apart horizontally and vertically in the concrete, the wire being ¼ inch in diameter. The cost of the work was:

For 680 cubic yards of concrete at $9.30 per cubic yard.....	$6,324 00
Macadam, appurtenances, etc.....	2,338 00
Total cost of bridge.....	$8,662 00

Fall Creek Bridges, Indianapolis.—The Melan arch was among the pioneers in steel concrete bridge construction. In the Melan construction steel I-beams are imbedded in the concrete, the base of the I-beam being from 3 to 5 inches from the intrados of the arch.

Fig. 97.—A Melan Concrete Bridge, Indianapolis, Ind.

The following description of the bridges built in 1900, over Fall Creek, Indianapolis, where Illinois and Meriden streets cross that creek, will illustrate the Melan system applied to bridges. The city had been burdened for years with the great expense of maintenance and repairs upon the many steel bridges within the corporate limits, until at last the authorities decided to replace the bridges at these points with permanent structures. Bids were invited upon three forms of bridges—steel girders, steel concrete and stone bridges. The bids upon steel bridges were the lowest, but were rejected because steel girder bridges lack both in beauty and durability. The lowest bid upon concrete was $105,340.00, while the lowest bid upon stone was $140,996.00, although close at hand there was an abundance of good building stone. One of the completed bridges, also one with the steel skeleton in place ready to receive concrete, is shown in figures 97 and 98.

The proportions of the concrete used in the back walls, spandrels and piers were, 1 part cement, 3 parts sand and 6 parts gravel. For the arches, 1 part cement, 2 sand and 4 parts gravel were used. The gravel and sand were taken directly from the bed of the stream.

Fig. 98.—A Melan Bridge in Process of Construction.

Fig. 99.—Goat Island Bridge, Niagara Falls, N. Y.

[illegible] Oconomowoc, Wis.

[illegible] every [illegible] the general out- [illegible] of the arch the steel members [illegible] 6 feet apart. High oval headed rivets, spaced 6 or 7 [illegible] into the top and bottom plates to give greater bond between the steel and concrete. There are 13 of these steel

ribs placed in the bridge. The whole arch is 38 inches thick at the crown and 70 inches near the haunch. The water is about 6 feet deep where the bridge stands and has a velocity of nearly 30 miles per hour. The bridge cost $102,070.00. Figure 99 shows the bridge.

Oconomowoc, Wisconsin.—A very neat concrete bridge was built in 1899 for Mr. P. D. Armour, Jr., at his summer residence near Oconomowoc, Wisconsin.* It has a span of 21 feet, a rise of 6 2-3 feet, and width of 15 feet. The arch is 5 inches thick, reinforced by three ribs 2 feet wide and 4 inches thick. A pair of flat iron bars, ¾ inch by 3½ inches, is placed at either side of the bridge conforming to the arch. These are latticed together forming steel trusses, the bottom of which are connected across the bridge by ½ inch round iron rods spaced 18 inches apart and ½ inch above the face of the concrete. Number 16 expanded metal, 2½ inch mesh, was laid over these rods. The concrete, composed of 1 part cement, 3 parts torpedo gravel and 4 parts of ¾ inch limestone, was then tamped in place. The surface coat was composed of 1 part cement, 1 part granite screenings and 1 part torpedo gravel. The facing is 1 inch thick and was spread upon the form before the concrete was laid. The centering was removed in nine days and heavy loads were hauled over the bridge. Figure 100 illustrates the beauty of the bridge.

Chatellerault Bridge, Vienne, France.—The Hennebique system of steel concrete is well illustrated in the construction of the Chatellerault

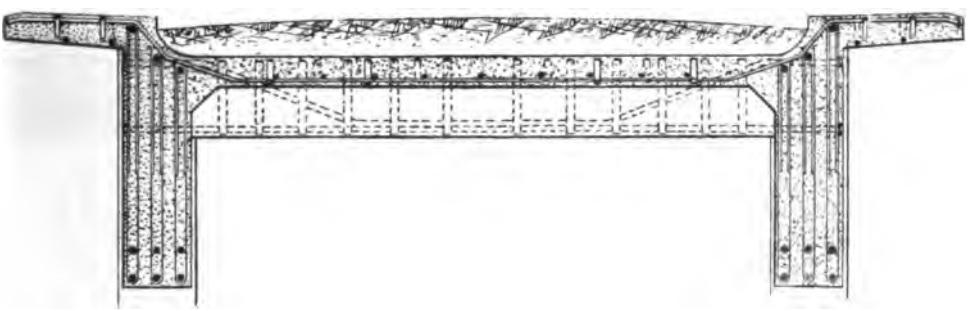


Fig. 101.—A Cross Section of a Bridge Showing Hennebique System.

bridge in France. This bridge has three spans, two of 131 feet and the other 164 feet in length. It was given several severe tests and records were taken of the deflections. A moving load consisting of road rollers and heavily loaded wagons, altogether equal in weight to 308,000 pounds, was driven across the bridge. These loads were again driven across after large wooden strips had been placed in the roadway in order to produce a series of shocks or blows. The maximum deflection upon the two shorter spans was 6 mm., and for the center arch 10 mm., or slightly

*Engineering News, Vol 42, P. 250.

less than 13-32 inch. Two hundred and fifty soldiers crossed, marching in quick step, and recrossed at "double time" in order to test the bridge for vibration, which it was found to stand remarkably well, Figure 101 shows the method of construction and figure 102 shows the complete bridge.

A seven span concrete bridge at Dayton, Ohio, completed in 1903, which is 56 feet wide and 588 feet long, cost $140,000.

Fig. 102.—Chatellerault Bridge, Vienne, France.

RETAINING WALLS.

In the construction of the Paris Exposition of 1900, it was found necessary to depress one of the streets near the exposition grounds to better accommodate the visitors. This street was to be depressed about 18 feet below the surface levels; and because of the character of the debris and filled ground through which the cut was to be made would have required expensive, heavy masonry for retaining walls if the ordinary gravity section were used; hence the engineers decided to use "armored concrete."

The retaining walls are divided into panels 19.7 feet in length, and extending back into the ground from the back of each panel, are three concrete buttresses. Connecting these buttresses at a point midway from the top to the bottom is a horizontal concrete beam from 4 to 9 inches thick and about 4 feet wide. The face wall rests upon another

horizontal beam similar to the above described beam and 4 feet 4 inches wide, which extends in front of the face wall about 2¼ feet and is connected by low buttresses to the face wall. This projection is about 2½ to 3 feet below the street level. The whole mass of concrete which is 4 to 6 inches thick is reinforced and connected by a system of Hennebique steel bars.

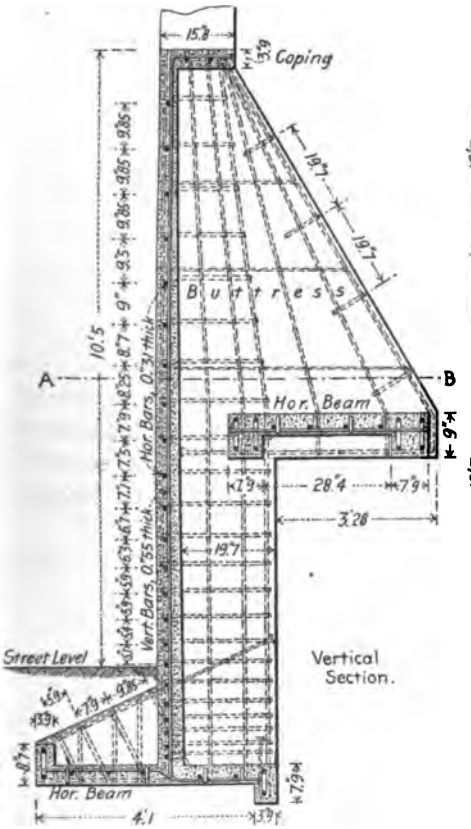
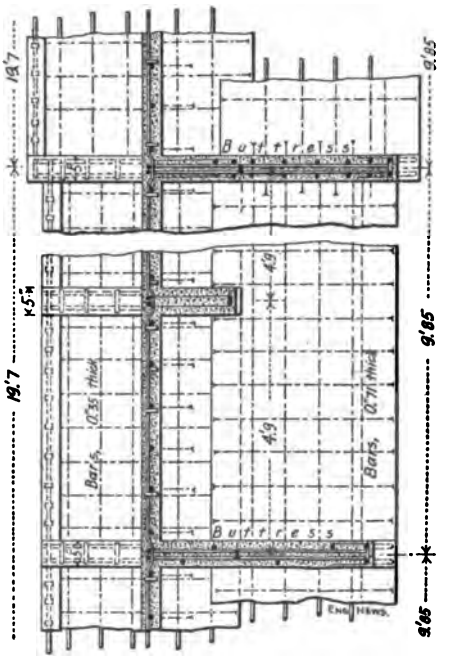


Fig. 103.—Section of Retaining Wall Used at Paris Exposition, Hennebique System.



Horizontal Section A-B.

Fig. 104.—Plan of Same.

By the arrangement of the horizontal beams the retaining wall is aided in supporting the thrust of the earth behind by the weight of the earth resting upon the beams. The location of the beams is such as to break up and reduce the thrust upon the thin vertical face wall. A portion of the tendency to overturn is also taken up by the forward portion of the lower beam and its bracing buttresses. The two figures 103 and 104 illustrate the construction better than the description.

In 1897, Messrs. Lehman and Moller invented a simple but efficient retaining wall which was patented in Denmark, Sweden and Norway, by a patent dated April 21, 1899. It consisted in a thin L shaped section of concrete, reinforced by steel, resting upon the shorter arm of the L and

depending upon the weight of the earth resting upon the lower arm, to overcome the thrust of the earth against the upright arm. See figure 105.

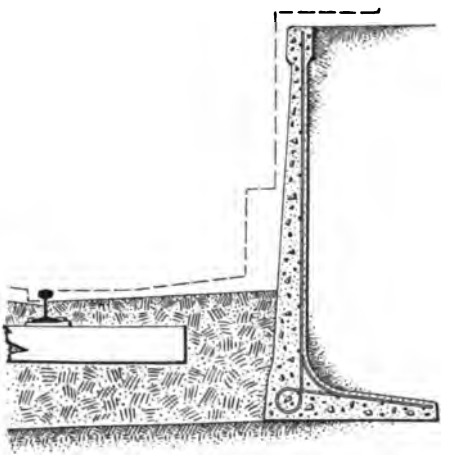


Fig. 105.—Section of Retaining Wall, Lehman's System.

In 1901, Mr. Frank A. Bone constructed a retaining wall upon similar lines, but not so light, at Blacklick, Ohio, upon which he secured patents in the United States. Figure 106 shows the cross section

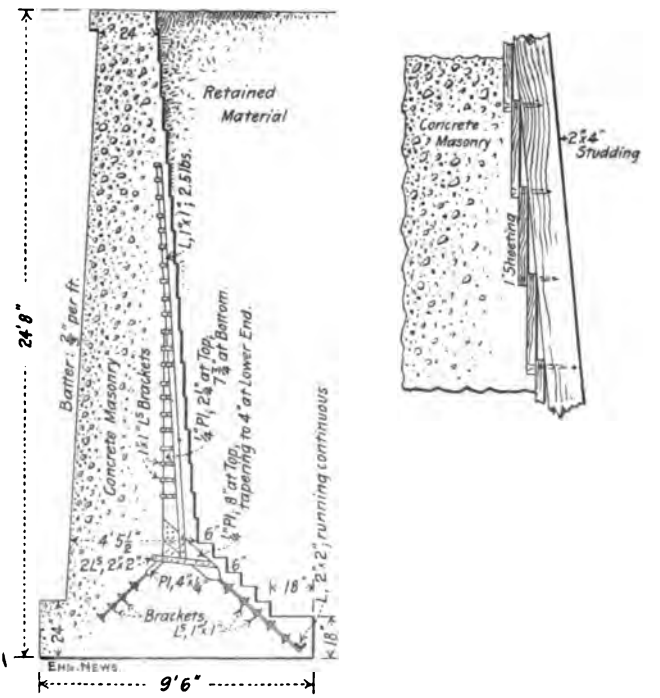


Fig. 106.—Section of Wing Wall, Bone's System, Constructed at Black Lick, Ohio.

of the Black Lick retaining wall. The steel ribs were spaced 4 feet apart throughout the wall and connected with 2 by 2 inch angle irons running horizontally through the mass as shown in the figure.

TUNNELS.

Reinforced concrete is used very often for the lining of tunnels. It is very similar, in general, to the lining of plain concrete heretofore described, its chief advantage being in unstable soils or in soft or stratified rock where falls or squeezes occur. Here the steel bars or members aid in supporting the pressure until the concrete has become perfectly set and also supply the tension members which aid the lining to withstand distortion.

Tunnel Under River Spree, Berlin.—A notable example of the use of steel concrete is in the tunnel under the River Spree at Berlin, Germany. It is 2,017 feet long and lies 40 feet below the level of the river. It is formed of a cast steel cylinder, 13.12 feet in diameter made into rings, set together and covered with 3⅛ inches of cement mortar upon the outside, and 4¾ inches upon the inside, with a heavy concrete floor. The steel rings vary from 1.64 to 2.13 feet in width.

SEWERS.

There are many forms of steel concrete used in sewer work. Expanded metal has been frequently used, being imbedded in concrete either just over the arch, or encircling the entire barrel.

Plain round and square bars, angle irons, I-beams and the Monier wire mesh have been used under various conditions.

One system that is being extensively used in Cleveland and Columbus, Ohio, will be briefly described here. It is known as the Parmley patent.

It consists of a system of two sets of round or flat steel bars imbedded in the concrete. The sets are staggered, one set being placed near the inner lining of the sewer, while the other set is near the outer side of the concrete walls. Both sets, however, are kept close to the inner surface of the crown of the arch and only extend downward to a point about one-fifth the diameter of the sewer below the center line. Longitudinal rods are also used to aid in distributing the stresses. To overcome the disadvantage of having the bars continuously in the way during the construction of the invert, the bars are cut into pieces and either punched for bolting or bent to engage hook and eye fashion. The shorter pieces are set into the concrete vertically, extending above and below the spring line, the arched piece being set in place when everything is ready to concrete the arch. For smaller sewers, the iron or steel rods, which are small, can be brought upon the work in merchantable lengths and cut and bent over forms as the work progresses.

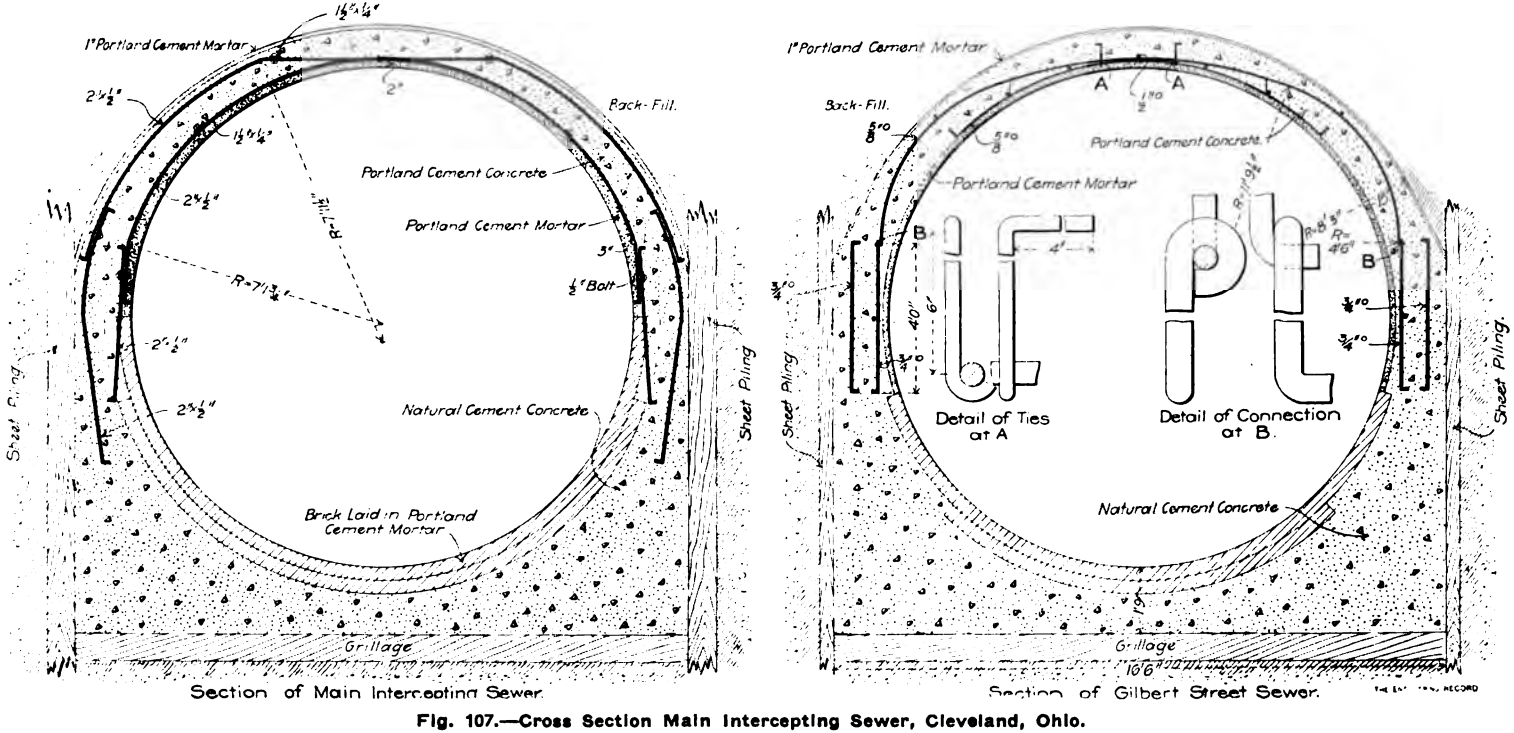


Fig. 107.—Cross Section Main Intercepting Sewer, Cleveland, Ohio.

Cleveland Main Intercepting Sewer.—The Main Intercepting Sewer in Cleveland, is built on the Parmley patent system. It is 13½ feet in internal diameter, and 3½ miles of it are under construction. For nearly two miles it is 35 to 44 feet deep and only 17 feet away from the center line of the Lake Shore and Michigan Southern Railway tracks. "Two staggered rows of 2 by ½ inch soft steel anchor bars, 15 inches apart on centers, were built into each side wall, and projected above it to receive the main tension bars." The transverse tension pieces were afterward bolted to these anchor bars and 8 lines of horizontal pieces 1½ by ¼ inch in dimensions were bolted to the transverse ribs.

After the steel was in place over the forms, 3 inches of cement mortar was laid upon the forms, enclosing the inner rods, then the concrete was rammed upon this mortar and the outside finished with one inch of cement mortar. The concrete for the arch was made of 1 part cement, 3 sand and 7½ crushed stone. The average price for this sewer is "about $62.00 per lineal foot as compared with $75.00 per lineal foot bid for ordinary brick construction." Figure 107 shows the work in detail.

A portion of the Central Relief Sewer in Columbus, Ohio, is being built on the same system of construction.

STEEL-CONCRETE WATER PIPE.

In a new water power plant at Champ, near Grenoble, France, 6,888 feet of a penstock, which conveys water to the turbines of the power plant, is constructed of steel concrete. It has a diameter of 10.82 feet and a uniform grade of 7 feet in the 1,000. The concrete portion was designed to carry a head of water of 65.6 feet. Iron bars from 0.43 to 0.87 inch in diameter are spaced at equal distances, longitudinally, around the barrel and outside of these and encircling them at right angles to the axis of the pipe are other bars from 0.24 to 0.47 inch in diameter. These longitudinal and transverse bars form meshes about 4.0 by 4.3 inches in dimensions. The pipe is from 8 to 10 inches thick. About 118 feet of pipe was built per day. See figure 108.

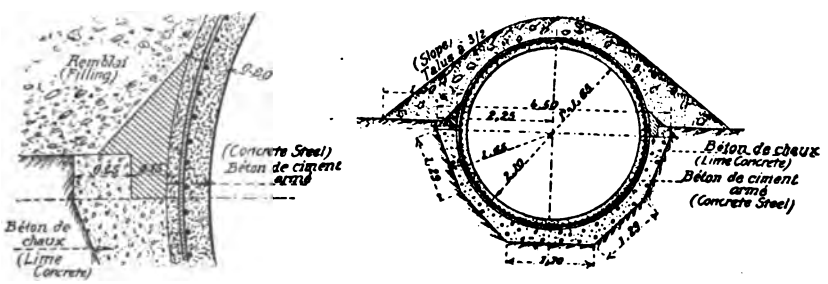


Fig. 108.—Detail of Concrete Steel Penstock.

Water Conduit for Jersey City.—The water supply for Jersey City, N. J.,* is carried for several miles through a large steel concrete conduit.

*Engineering News Aug. 30, 1900.

Fig. 109.—Section of Water Conduit, Boonton, N. J., Showing Weight Carried During Test.

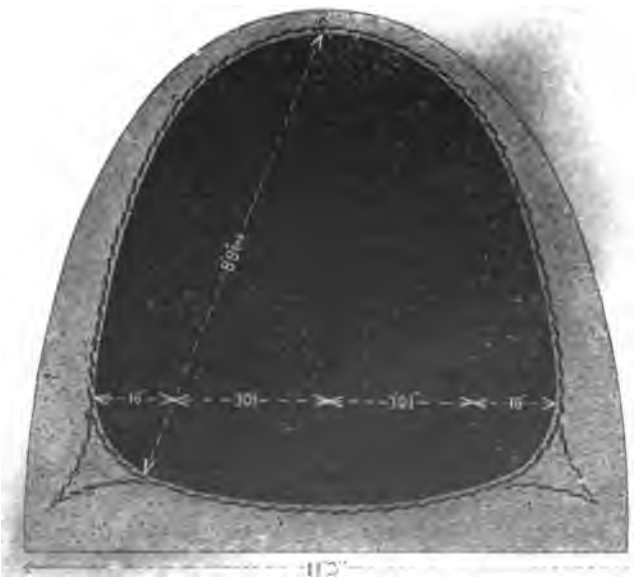


Fig. 110.—Method of Reinforcing Water Conduit at Boonton, N. J.

Several forms were designed, but after a very severe test, the form illustrated in figure 109 was adopted and used. The conduit is 8 feet, 9 inches wide, and the same in height. The crown of the arch is 5 inches thick, the haunches 10 inches thick, and the middle base, 8 inches thick. It is reinforced with expanded metal as shown in figure 110. It required one cubic yard of concrete per lineal foot of conduit.

It may be of interest to give a brief description of the test shown in the illustration. A test section 10 feet long of full size was erected in May, 1900. It was built of concrete composed of 1 part Portland cement, 2 of sand and 5 of broken stone from 1 to 1½ inches in size. Thirty days after completion it was tested. The test began at 2:45 p. m. by laying on railroad rails, one by one. "At 5:28 p. m., with a load of 21½ tons, fine horizontal cracks began to show along the extrados, but no any further signs of weakness."

"When the load had been increased to 25 tons, three rails, weighing approximately 1 ton, were twice dropped on the rails on top of the arch over one end of the latter. The cracks were slightly widened and new fine cracks showed in the intrados and haunches, running along the inside of the conduit section.

The total deflection at the crown of the arch was 7-16 inch. The test section stood under the 25 ton load for several weeks without showing any further signs of weakness.

POSTS.

The American Cement Post Company of Athens, Mich., manufactures a steel or iron concrete post. Two corrugated iron straps run

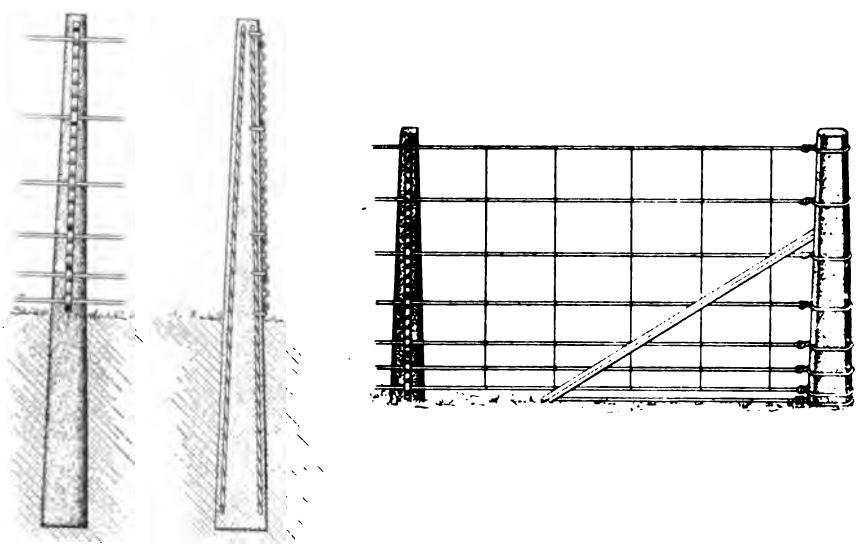


Fig. 111.—Concrete Fence Post, American Cement Post Company's System.

Fig. 112.—Shell for Raymond Concrete Pile, 20 Feet Long, Weighing 70 Pounds.

the entire length of the posts, doubling over at the top and bottom as shown in the accompanying illustration, figure 111. Wire is wrapped around one of these straps and looped out sufficiently beyond the surface of the cement to form attaching loops, either for barbed or net wire fencing, or for common fence boards. A special machine is used for compressing the concrete into the forms.

Corner posts are made 8½ feet long, 8 inches square at the base, and 6 inches square at the top, and weigh about 500 pounds. Such posts cost from 30 to 35 cents a piece. The line posts are much lighter, being 7½ feet long, 3½ inches square at the bottom, 2¼ inches at the top and weighing about 60 pounds. These posts cost from 8 to 12 cents each.

PILES.

Several kinds of concrete piles have been employed in construction. One of the earliest uses of steel concrete piles was in the form of a steel tubular casing or wrought iron pipe sunk through yielding ground or sand to good bearing and then filled with concrete. This form was especially adapted for small highway or railway bridges, and has been quite extensively used.

Cushing's pile foundation, which consisted in driving a group of woden piles, encasing them within an iron casing extending below low water line, and then filling in all the space within the casing and around the piles with concrete, has long been used for bridge pier foundations.

Raymond Pile.—The Raymond pile consists of a steel shell 20 feet or more in length, 18 inches in diameter at the butt and 6 inches near the point, which is driven with a collapsable core. When the pile is driven, an extra blow given to one portion of the core drives in this portion collapsing the core so it can be drawn, leaving the shell in place. The casing is then filled with concrete. The cost is estimated at 50 cents per foot of pile, or $1.00 per foot in place.

The new Carnegie library building, Aurora, Ill., is being built upon a foundation supported by the Raymond pile reaching to bed rock. These piles are encased in No. 20 sheet iron filled with Portland cement concrete of the proportions 1 cement, 2 sand and 4 crushed stone. Figures 112 and 113 illustrate the Raymond pile.

Hennebique Armored Piles.—The Hennebique armored pile consists of four round iron rods spaced 9 or 10 inches apart in a square, and tied together about every three feet with iron bars. These pieces are set in forms and concrete cast about them to form a post 14 inches square and of any desirable length. At the bottom they are shod with steel shoes as shown in the accompanying illustration. These have been used in England and upon the continent. They are especially valuable along the salt water harbors, as they can not be injured by the teredo. Such piles are

also of great benefit where the rise and fall of the water level hastens the decay of wooden piles. Figure 114 illustrates this form.

Fig. 113.—Raymond Pile Core, Which Collapses and is Withdrawn After the Shell is in Position.

ELEVATED RAILWAYS, TIES, TRESTLE BENTS, TURNTABLES, ETC.

Elevated Railways.—The St. Louis Expanded Metal Fireproofing Company have designed a steel concrete structure for elevated railroads which they claim can be constructed for less money than can a steel structure. The maintenance of such a structure should be less than one of steel and the beauty would certainly be greater. Figure 115 illustrates their design.

Ties.—In many localities, railroad ties are not easily procurable. At best they decay and wear out rapidly. Because of this, railroad

officials have long been looking for a good durable substitute for the wooden tie.

Mr. O. J. D. Hughes, U. S. Consul to Italy, reports the use of concrete ties by the Adriatic railway line. These ties are of steel concrete, 8½ feet long, triangular in section, with apex of angle up, having full width at the rail seat. Bottom width of tie is 7⅞ inches, and the weight 287 pounds. The iron bars used weigh 88 pounds. The ties cost $2.20 apiece, about twice what a wooden tie costs. These ties have been in use for two or three years, and the railway officials, judging from the experience they have had, believe the ties will last thirty or forty years.

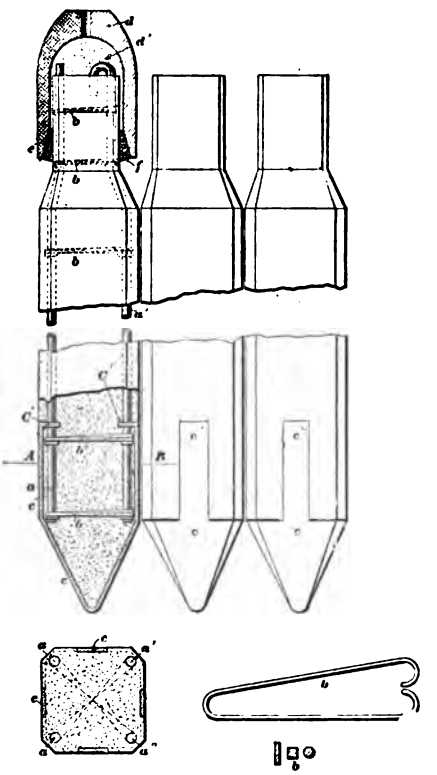


Fig. 114.—Concrete Pile, Details of Construction According to the Hennebique System.

The Pittsburg, Ft. Wayne and Chicago Railway has been experimenting with such ties at various times for four or five years. Their first attempts were not successful, the experimental work causing the ties to cost about $8.00 apiece. Afterward, modified forms and more systematic methods of construction, led them to believe that more durable ties could be built for about $1.00 apiece. The improved tie consisted of two channel bars 7 feet long, for the top and bottom of the tie, imbedded in concrete. Metal struts under the rail seats braced the two bars. A short piece of channel forms the rail seat through which pass

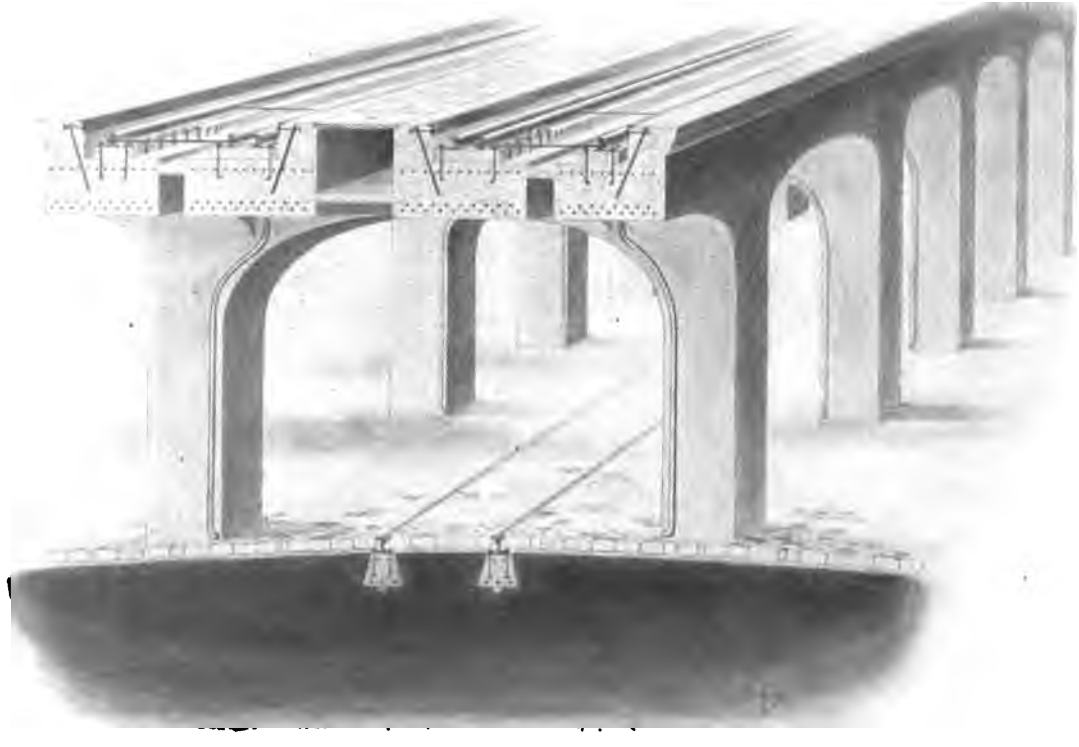


Fig. 115.—Proposed Concrete Elevated Railway System.

Fig. 116.—Concrete Ties on a German Railway.

the anchor bolts. The whole tie is 7 feet, 8 inches long, 8 inches thick and 5 inches wide on top and 8 inches wide at the bottom. It weighs complete, 300 pounds.

Quite a number of railroads are testing what can be accomplished with concrete ties, but as yet no road has definitely determined the durability of such construction. Figure 116 shows concrete ties in use on a German road.

Trestle Bents.—In the yards of the American Smelting and Refining Company, Perth Amboy, N. J., the railway tracks run over the coal and ore bins. Concrete trestle bents or walls support the tracks, forming the dividing walls for the ore bins. The bents are erected upon pile foundations, are 12 feet apart, 6 feet, 9 inches high and 12 inches thick at the top and 16 inches at ground level. At the bottom, the bent spreads out to form a footing 24 inches thick which rests upon four 13 inch piles driven 25 feet to a firm bearing. Vertical ⅜ inch rods are imbedded in the concrete in two planes 8 inches apart, the rods being 18 inches apart in the plane. The forms were made of dressed lumber and allowed to remain in place 48 hours after the placing of the concrete. The concrete was a mixture of 1 part cement, 2 sand and 4 parts slag.

The cost was reported to be about the same as equivalent wooden bents with mud-sills.

Turntables and Ashpits.—A number of railroads have used concrete walls for turntables and ashpits. In the latter, especially, concrete is given a severe test. Hot cinders and ashes fill the pit and then after the walls have become heated, cold water is thrown in to quench the ashes. The sudden changes from heat to cold are very severe upon materials so unelastic as stone or concrete. Acids are also formed from the sulphurous coal ashes, yet with all of these tests, concrete has proved quite satisfactory.

At Bureau, Ill., the C. R. I. & P. railroad has constructed a five stall round house of concrete. The walls are 18 inches thick. After the forms were removed, the outside was washed with a cement washing, the inside was left as it came from the forms.

ELECTRIC FOUNTAINS.

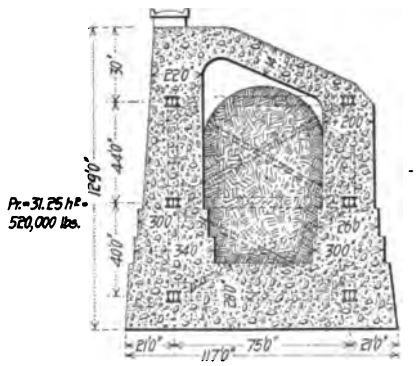
The electric fountain at Willow Grove, Philadelphia, is constructed of concrete. It has been in operation for six years or more and seems in a fair state of preservation. One or two contraction cracks and a few places in the floor of the water basin that sounded hollow, indicated that the surface coating had not made a good union with the body of concrete. The superintendent said that no repairs had been made in the three years in which he had been in charge. The conditions are such as to give concrete a very severe test. Dry and wet, heat and cold, expansion and contraction, weathering and freezing all uniting to work destruction.

PRISON CELLS.

Concrete is used to great advantage in the construction of jail and prison cells. The steel reinforced walls are exceptionally strong and take up but small space. When floors, walls and ceilings are all made of steel concrete, it becomes a very easy matter to thoroughly cleanse a whole corridor of cells. It also prevents the spread of vermin. In cleansing, the hose with water under pressure may be used to advantage. It is also a great protection against fire.

STEEL-CONCRETE DAMS.

Fielding System.—*Mr. J. S. Fielding, Pittsburg, Pa., suggests a novel method of reducing the cost of dam construction by reducing the amount of expensive material used. He suggests using reinforced concrete constructed in rough rectangular compartments, which can be filled with earth or loose stone to give gravity stability to the dam. Figure 117 illustrates his design. The fore and back walls are connected every ten to twenty feet by cross walls in which the tie members are imbedded.



Proposed Steel and Concrete Section.

Fig. 117.—Proposed Design for Hollow Concrete Dam.

Theresa Dam.—A hollow concrete steel dam was lately constructed at Theresa, N. Y.† It is 120 feet long and 11 feet high. It consists of a solid concrete toe, a series of solid concrete buttresses 12 inches thick spaced 6 feet center to center, and an inclined up-stream concrete face 6 inches thick, reinforced with Thacher bars and expanded metal. In the toe and buttresses the concrete was proportioned 1 cement, 3 sand and 6 stone, while for the water-face of the dam the proportions were 1 cement, 2 sand and 4 broken stone. Figure 118 clearly shows the construction and illustrates the great saving of material in such a form of construction.

*_Engineering News_ Nov. 16, 1899.
†_Engineering News_ Nov. 5, 1903.

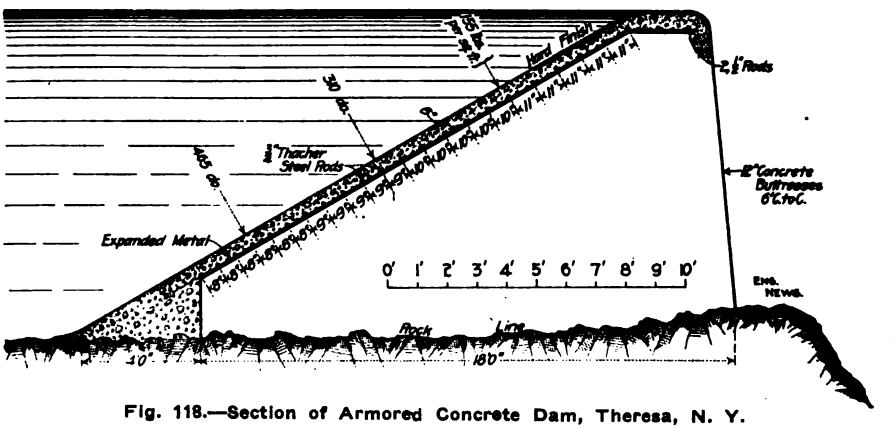


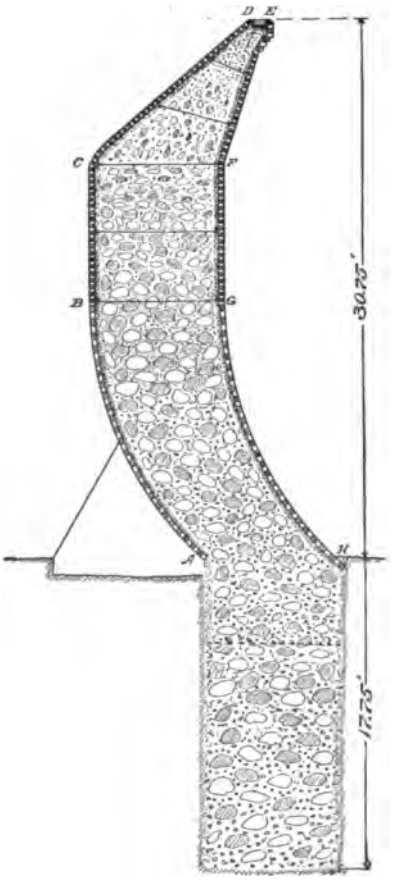
Fig. 118.—Section of Armored Concrete Dam, Theresa, N. Y.

Ithaca Dam.—A bold concrete dam was recently constructed at Ithaca, N. Y., which it is worth while to illustrate at this point in order

Fig. 119.—View of a Dam at Ithaca, N. Y.

that confidence may be strengthened in the value of concrete for structures placed under trying conditions.

The Ithaca Water Works Company wished to increase and develop their source of supply for the city of Ithaca but felt that they could not put in sufficient capital to build a large dam with a gravity section. Several plans and estimates were made but all were too high in price.



Vertical Section on Center Line.

Fig. 119a.—Cross Section of the Ithaca Dam.

Mr. Gardner S. Williams, Associate Professor of Civil Engineering at Cornell University, was engaged as consulting engineer to prepare plans and he designed the dam illustrated in figures 119 and 119a, accomplishing a reasonably large storage for a minimum construction. The dam was originally designed to be 90 feet high but was reduced to its present height in building. It is built in a narrow slate or shale gorge about 90 feet wide at the point where the

dam is located. The dam is built of concrete reinforced at the face and back with 3 by 3-16 inch longitudinal steel bands spaced 4 feet apart and interlaced with wire mesh.

Five-eighth inch tie rods connect the two systems of reinforcement. Both back and face of dam are faced with vitrified brick or block. The dam is about 7½ or 8 feet thick and is built in a partial dome shape, convex side upstream. The radius of the horizontal curvature is 100 feet.

During construction it successfully withstood a severe overtopping flood. Messrs. Ross F. Tucker and Thomas M. Vinton built the dam.

Fig. 120.—Sidewalk Composed of Reinforced Concrete Slabs, According to the St. Louis Expanded Metal Company's System.

METALLOID SIDEWALKS.

The St. Louis Expanded Metal Company have a new design for sidewalks which would seem to have some commendable features. By the use of sheets of expanded metal, concrete sidewalk blocks five or six feet square and about 2 inches thick are made at some central factory, and the blocks are then shipped to the site ready to set in place like stone slabs.

The foundation consists of two trenches filled with cinders upon which the concrete stringers at the edges of the slabs rest. The center portion of the block does not rest upon the ground, hence is not affected by the heaving due to frost.

It is claimed that this form is no more expensive than the usual concrete walk and it can be laid at any season of the year, without interrupting traffic. Figure 120 illustrates the method.

FIRE PROOFING, FIRE TESTS AND FIRES.

The fire proof qualities of concrete and concrete-steel are becoming better known each year. Theoretically, a good fire proofing material must have two qualities, it must be able to resist sudden changes of temperature within its own structure without disintegration and it must be a non-conductor of heat. The porous nature of concrete, and especially of cinder concrete, prevents heat from rapidly penetrating the mass. A comparatively small section of cinder concrete will prevent the temperature of enclosed steel from becoming high enough to destroy its strength or to badly expand or warp it. Tests seem to prove that concrete has both of the desirable qualities.

Mr. E. Lee Heidenreich, the agent for the Monier system in the United States, says he has heated Monier plates 2 inches thick, one foot wide and three feet long to a temperature of 1,200 degrees, Fahrenheit, and cooled them off by plunging them into cold water without showing any deteriorating effect. This would indicate not only that the concrete could successfully resist great sudden changes in temperature, but also that the coefficient of contraction and expansion of concrete and steel are nearly similar. For if this were not true, the variation of expansion and contraction of the metal in the plate would have ruptured the concrete. The test mentioned in the description of the Roebling system of reinforced concrete also bears witness to the power of concrete to resist the destructive effects of fire.

New York City Fire Tests.—In 1901,* the Department of Buildings of New York City conducted a series of fire tests quite severe in character, which nearly every firm in the tests, using Portland cement in any form, successfully passed. The department specified the

*_Engineering News_ December 26, 1901.

Fig. 121.—Ruins of the McMahon Cracker & Biscuit Company's Building, Burned October 8th, 1901, at Chicago, Ill. Only the Armored Concrete Work Remains Intact.

method of procedure, the size and shape of the house to be constructed and the arrangement to be made for firing.

The partitions and test walls were erected by the firm interested in the particular fire proofing submitted for test.

The houses were all 9½ by 14½ by 12 feet high. The test walls were from 2 to 4 inches thick. The houses were built with a flue in each corner to provide for thorough circulation and quick heating. Grates were built 3 feet above the foundations and heavy protected doors were provided so that access was given for firing and observations. Kerosene, pine and hard wood were used for fuel. The temperatures were to be kept from 1,700 degrees to 2,100 degrees, Fahrenheit, for one hour and then water from the city mains was to be thrown on to the heated walls for 2½ minutes through fire nozzles with the regular city pressure.

The test that is of particular interest here was the one made upon the Sprickerhoff partition. This partition was built of concrete blocks 3 inches thick plastered one-half inch thick on both sides with King's Windsor "browning mortar." The blocks were composed of 1 part Portland cement, 1 part sand, and 5 parts steam ashes—the blocks being laid in a cement mortar of 1 cement to 2 sand. The temperature reached 1,868 degrees, Fahrenheit. Water was applied which stripped the plaster, but left the concrete portion unharmed and as straight and plumb as before the test.

There is nothing so convincing, however, as the actual test upon buildings in service.

McMahon Cracker and Biscuit Company's Building.—The building of the McMahon Cracker Company, located in Chicago, burned on October 8, 1901. The entire structure was totally wrecked, except the portion holding five large bake ovens, each weighing 200 tons. These were situated from the third to the fifth floors and were supported by steel columns protected by a concrete shell composed of 1 part Louisville natural cement and 4 parts soft coal cinders, enclosed in a wire form plastered with cement mortar on the outside. The steel work in the other portion of the building was twisted and ruined and the walls, left unsupported, fell. But the heaviest portion of the building supported by concrete protected steel remained standing. Figure 121 shows the results of the fire.

The Borax Company's Building.—The Pacific Coast Borax Company's building situated at Bayonne, N. J., was destroyed by fire, April 11, 1902. A large portion of the main building— the footings, walls, posts, girders, floors and a few partitions—were of steel concrete. The floors were concrete slabs 4 to 5 inches thick resting on and being monolithic with concrete beams, which were 4½ inches

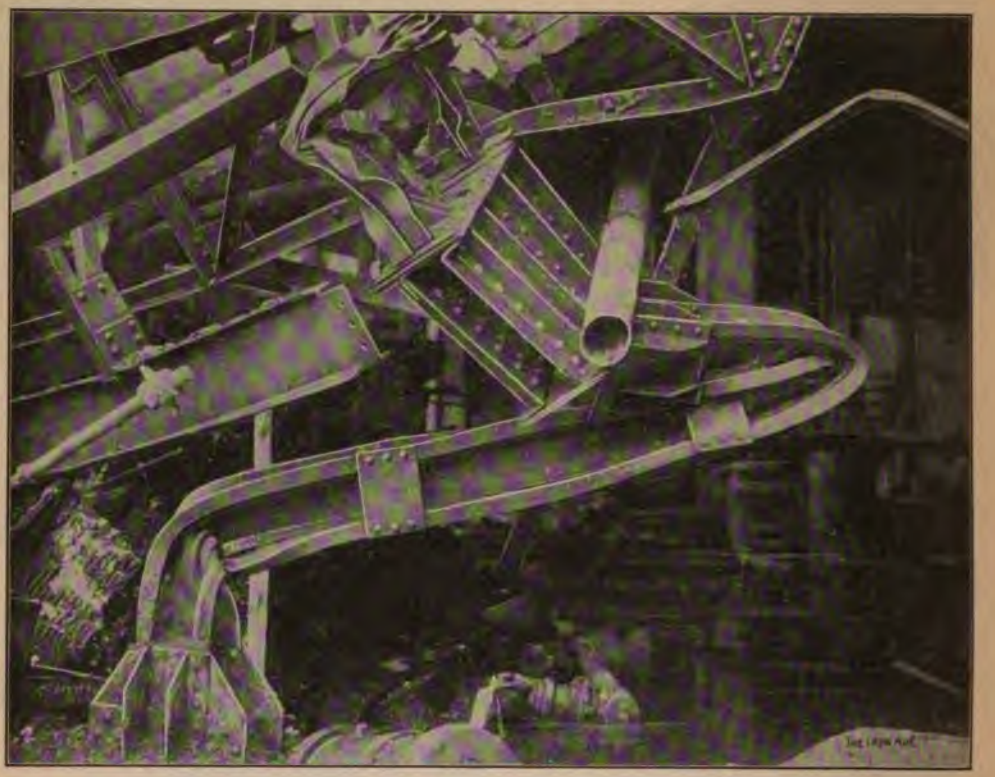


Fig. 122.—The Effect of Fire on Steel Construction. The Pacific Coast Borax Company's Works, Bayonne, N. J.

Fig. 123.—Effect of Fire on Reinforced Concrete Construction, Pacific Coast Borax Company's Works. The Fire was Exceptionally Hot at This Point.

wide, 28 inches deep and 24 feet long, spaced 3 feet center to center. The columns were of solid Ransome steel concrete, being 21, 19 and 17 inches square for the first, second and third stories, respectively. The walls were 16 inches thick, having 9 inch hollow spaces in the center. The concrete was made of Atlas Portland cement and crusher run of basaltic rock passing a 1 inch ring screen. No sand was used, the fine crushed basalt taking its place. The proportions varied in different portions of the work from 1 part cement and 5 crushed stone to 1 cement and 6½ stone.

One wing where the crystallizing tanks were placed was of steel frames with wooden walls, partitions and fixtures. Much inflammable material was stored all through the building at the time. The roof was of wooden beams and light supports, with board and tar covering. There were many wooden partitions in the main building, much wooden framing for the shafts, machinery supports, stairways and bins.

The heat of the fire was sufficient to fuse copper in several places in the building. All steel posts and girders were warped out of all semblance to their proper shape. Several large tanks set upon the roof, one a concrete tank 6 by 6 feet and 50 feet long, weighing 33 tons, fell through to the fourth floor without doing any injury. The clear fall from roof to floor was 14 feet. One steel tank weighing 18 tons fell corner-wise, apparently, and that cracked two or three concrete floor girders and broke a small hole through the floor. With the exception of the cracked floor beams, no damage was done to the concrete portion of the building except to crack off the plaster here and there and to smoke up the walls and ceilings so that a coat of paint or plaster was required to put them in presentable shape.

The floors held three and four inches of water after the fire without showing any leakage.

Figure 122 shows the results of the fire in the one story portion of the building where there was not a great amount of combustible material. Figure 123 shows the condition of the concrete at the point where the fire was the most intense and where the hole was punched in the floor doing the greatest damage.

The test was so conclusively in favor of concrete for a fire proof material that the company in rebuilding made all of their partitions, the roof, bins and the machinery and shafting supports out of concrete.

The writer visited the works on August 28, 1902, just before the rebuilding was completed; the plant had been in operation, however, for some months, as it took but little work to get the main building in condition to operate the plant. The work in progress was the laying of the roof.

In making the roof, planed boards were used for the forms. They were carefully put up and thoroughly supported. A thin coat

of white plaster one-half inch or less in thickness, apparently carrying some plaster of Paris, was spread upon the forms and then the iron bars and concrete were put in place. The white mortar acted as a plaster or surface coat for the underside of the roof.

Within the building heavy machinery, crushers, filter presses, tanks, etc., were set upon the floor or hung from the ceiling with no extra strengthening attempted. Borax, weighing 340 pounds per barrel, was stacked three barrels high over large areas. In fact, much of the floor, so the general manager said, had been tested in actual service by loads of 1,000 to 1,650 pounds per square foot.

Baltimore Fire.—The Engineering News* employed several experts to investigate and report upon the fire proof construction within the area swept by the great Baltimore fire of February 7, 1904. Extracts from these various papers read: "Comparing the efficiency of concrete and the hollow blocks as fire-proofing materials, there is no doubt but that the concrete made from steam boiler cinders and Portland cement, made the best showing."

"Generally speaking concrete and terra cotta protected successfully the steel columns."

"As fire and water resisting materials, terra cotta and concrete have given a very good account of themselves."

"The buildings were all gutted, but the concrete floors were all apparently in first-class condition. The iron work was not exposed and the concrete did not appear to be disintegrated."

"The concrete construction† (speaking of the Fidelity and Guaranty Company's building) endured the fire practically uninjured, a notable demonstration being the fact that the cantilever extensions of the floors in front and rear remained intact, and the attic floor carried a tier of columns reaching to the roof which it had never been designed to support."

"In a few cases where the heat was the greatest, fine surface cracks were seen in the beams and ceilings and small portions of the concrete had flaked off, but nowhere sufficient to indicate serious injury to the structure."

One of the floors in this building was afterward tested by loading it with a uniformly distributed load of 225 lbs. per square foot and it only showed 1-16 inch deflection under the load. The concrete used in the United States Fidelity and Guaranty Company's building was composed of 1 cement, 3 sand and 5 crushed granite. Two other buildings were of so called fire proof construction.

*_Engineering News_ March 3, 1904.
†_Engineering Record_ March 18, 1904

CHAPTER V.

SPECIFICATIONS FOR CONCRETE MATERIALS.

In the following pages the effort has been made to show what safeguards may be thrown around the use of cement for the numerous class of structures which have been described in the foregoing chapters. It will be, of course, undertsood, that the framing of specifications for a piece of work of great importance where either large sums of money or human life is involved in any failure of the structure as in dams, bridges, floors, etc., is a work which properly belongs to the trained engineer and to him alone. Each piece of work of this sort must be made a special study and take into consideration all the local and unusual features of the case as well as considerations based on the normal qualities of the materials.

But there are a very large class of uses of less importance, where no such results depend, and there is no reason why the architect, contractor, builder, owner and in fact any person of intelligence, but devoid of engineering training, may not with safety and satisfaction to himself, prescribe the conditions under which the cement structure shall be built.

Accordingly a number of specification forms which have been prepared by skilled engineers and cement users, are here reproduced in order to serve as models upon which others may draw their contracts.

CEMENT.

The cement may be of any brand of American or foreign Portland cement which will meet the requirements of these specifications.

Condition of Delivery.—It must be delivered in original packages labeled with the brand and the name of the manufacturer. These packages may be either barrels or bags, but must be well protected in either case from air and moisture. Any broken packages may be rejected or used at the option of the engineer in charge of the work.

Time of Delivery.—The contractor shall furnish the cement upon the work at least ten days before it is to be used, in order that time may be given to make the necessary tests.

Housing.—It shall be stored in dry, well ventilated buildings for work of any magnitude; and for work of less importance it shall be safely stored and protected from moisture in any form.

TESTS OF PORTLAND CEMENT.

The cement shall stand the following tests; any that fails to meet these tests will be rejected and the contractor shall immediately remove the same from the work.

Soundness. —Two pats of neat cement, with thin edges, will be made upon glass plates, and allowed to attain permanent set in moist air. Twenty-four hours after making, one pat will be placed in water having a temperature between 50 and 70 degrees F., and must withstand indefinite exposure without checking, softening or distortion. The other pat will be placed in some form of a steamer over cold water, which shall be brought to the boiling point and maintained at this temperature for three hours and then allowed to cool slowly. The pat shall not show any signs of distortion, cracking or softening under this test.

Fineness. —The cement shall be so finely ground that after being thoroughly dried by heating it 94 per cent. shall pass through a No. 100 standard sieve, woven from No. 40 Stub's wire guage.

Activity. —Initial set shall not occur in less than 40 minutes, and final set in less than one hour and 30 minutes nor more than six hours. The time of setting shall be determined by Gilmore's wires, or Vicat's needle.

Tensile Strength. —The standard section of briquette shall be used. The neat cement shall be mixed into a rather dry, stiff paste by the addition of from 17 to 20 per cent. of its weight of water. In a mortar of sand and cement, water to the amount of 10 to 13 per cent. of their combined weights shall be used, the amount depending upon the character of the cement and sand. The mortar shall be firmly pressed into the molds with the thumbs, filling the molds in three layers of about equal thickness and smoothing off both sides with a trowel. Briquettes shall remain in moist air for twenty-four hours and the remainder of the time, until tested, they shall remain in water at a temperature of about 60 to 65 degrees F.

Seven day tests of neat cement shall show not less than 450 pounds per square inch, and not less than 550 pounds for 28 day tests. Briquettes made of 1 part cement to 3 parts standard sand shall stand a test of 150 pounds per square inch at seven days.

SPECIFICATIONS FOR SAND.

All sand used for mortar shall pass a No. 10 sieve and 80 per cent. of it shall be retained upon a No. 74 sieve. It shall be a silicious sand, as sharp as can be obtained within reasonable limits of cost. It shall be free from all vegetable and organic matter, and shall not contain more than 10 per cent. by weight, of clayey or loamy material.

SPECIFICATIONS FOR STONE.

The aggregate shall consist of crushed trap rock, granite, hard limestone, or other material equally hard and durable which shall meet the approval of the engineer. The broken stone shall be free from vegetable or organic matter in any shape and free from mud and dust or from lumps of clay or clay covered fragments. When sand is to be used in the concrete, the stone shall be screened to pass through a (—) inch ring and retained by a screen of ¼ inch rings. The stone should be thoroughly wet before mixing with the mortar. When it is desired to use screenings with the crushed stone, the proper proportion of sand to be used shall be determined by analysis.

SPECIFICATIONS FOR CONCRETE.

Proportions.—The concrete shall consist of one part cement, 2 to 4 parts of sand, and 4 to 10 parts of crushed stone measured by loose volume. (The proportions must vary to suit the character of the work and the requirements which the concrete must meet.)

Mixing.—The sand and cement shall be thoroughly mixed dry, then sufficient water added to make a plastic or wet mortar and the whole thoroughly mixed again. The stone, having been previously wet down, shall then be added and the whole mass thoroughly mixed until every particle of stone is coated with mortar. The concrete thus mixed should be immediately placed in position and rammed until excess mortar shows over the entire surface. (Where surfaces are to be exposed, either a facing of 1 cement to 2 sand shall be used and placed in position as the mass of concrete advances, or else the stone should be forced back by thrusting down flat bladed shovels along the face of the form, thus allowing the richer mortar to run in next the form which makes a smooth impervious surface.) No concrete which has attained partial set shall be used. The engineer will be guided by the tests in establishing a limit of time beyond which any concrete once mixed shall not be used in the work.

SPECIFICATIONS FOR PORTLAND AND NATURAL CEMENT.

Adopted May, 1903, by the American Railway Engineering and Maintenance of Way Association.

PORTLAND CEMENT.

1. **Definition.**—Portland cement is a product of the mixture of clay and lime-carbonate in definite proportions, calcinated at a high temperature and reduced to a fine powder.

2. **Packages.**—Cement shall be packed in well-made wooden barrels lined with paper, or in strong cotton or paper sacks. Each package shall be plainly marked with the brand and name of the manufacturer, and the net weights shall be exact and uniform.

3. **Weight.**—One barrel shall contain not less than 376 pounds of cement, and four sacks shall be equivalent in weight to one barrel.

4. **Condition.**—All cement shall be delivered in sound packages, undamaged by moisture or other causes.

5. **Storage.**—Cement must be stored until used in a perfectly dry place in such manner as will insure it from all damage.

6. **Rejection.**—All cement failing to meet the requirements of the specifications may be rejected, and all rejected cement, whether damaged or rejected for other causes, shall be removed at once from the company's property.

7. **Tests.**—All cement shall be subject to the following tests:

(1). The selection of the sample for testing, the number of packages sampled, and the quantity taken from each package, must be left to the discretion of the engineer, but each sample should be a fair average of the contents of the package from which it is taken. At least one barrel in every ten should be sampled.

(2) Cement in barrels should be sampled through a hole made in the center of one of the staves, midway between the heads, or in the head, by means of an auger or sampling iron similar to that used by sugar inspectors. If in bags, it should be taken from surface to center.

(3) All samples should be passed through a sieve having twenty meshes per linear inch in order to break up lumps and remove foreign material. For determining the characteristics of a carload of cement the individual samples may be mixed and the average tested; where time will permit, however, each sample will be tested separately.

8. **Fineness.**—Not less than 94 per cent. of the cement tested shall pass through a No. 100 standard sieve. The standard sieve shall be circular, about 20 cm. (7.87 ins.) in diameter, 6 cm. (2.36 ins.) high, and provided with a pan 5 cm. (1.97 ins.) deep and a cover. The wire cloth in the sieve to be woven (not twilled) from brass wire having a diameter of 0.0045 ins. This cloth to be mounted in the frame without distortion; the mesh should be regular in spacing and for a No. 100 sieve shall contain not less than 96 nor more than 100 meshes per linear inch. The cement to be thus tested shall be thoroughly dried at a temperature of 100° C. (212 degrees Fahr.) before sieving.

9. Set.—(1) Initial set shall not occur in less than thirty (30) minutes.

(2) Final set shall not occur in less than one hour nor more than ten hours.

(3) The time of setting shall be determined by means of the Vicat needle apparatus as recommended by the Committee of the American Society of Civil Engineers upon uniform tests of cement in conjunction with the Committee of the International Association for Testing Materials.

(4) Using a paste composed of neat cement and water, of normal consistency, the initial set is said to have commenced when the needle ceases to pass a point 5 mm. (0.20-in.) above the upper surface of the glass plate in the Vicat apparatus, and is said to have terminated the moment the needle does not sink visibly into the mass.

(5) The paste is of normal consistency when the cylinder of the Vicat apparatus penetrates to a point in the mass 10 mm. (0.39-in.) below the top of the ring.

(6) The amount of water required to make a paste of normal consistency varies with different cements, but will be found to be approximately 20 per cent. of the weight of the cement. It should have a temperature of 70 degrees Fahrenheit.

10. Soundness.—(1) A pat of neat cement 2½ to 3 inches in diameter, ½-inch thick at center, tapering to a thin edge, and allowed to take its final set in moist air, must withstand indefinite exposure in water or air at any ordinary temperature without checking distortion or softening,

(2) A pat of neat cement as above, placed in water, which shall be slowly raised to the boiling point and then maintained in that condition for three hours and allowed to cool gradually, shall not show any signs of checking, distortion or softening. The same result should follow exposure to steam not under pressure for three hours. This test may or may not be cause for rejection, at the option of the engineer in charge.

11. Tensile Strength.—(1) The briquette used in testing shall be formed in molds of the size and form now in customary use and recommended by the American Society of Civil Engineers, the stress to be applied at a uniform rate of 600 pounds per minute until fractured.

(2) All briquettes of neat cement are to be made from paste of normal consistency in the following manner: The molds should be filled with the paste as soon as it is thoroughly mixed and tempered, the material pressed in firmly with the fingers and smoothed off with a trowel without ramming; the material should be heaped up on the upper surface of the mold, and in smoothing off the trowel should be drawn over the mold in such a manner as to exert a moderate pressure upon the excess material. The mold should then be turned over and the operation repeated upon the other side.

(3 Briquettes for twenty-four hours tests shall be allowed to set twenty-four hours in moist air.

(4) Briquettes for seven and twenty-eight day tests shall be allowed to set one day in moist air and remainder of period in water.

(5) All briquettes are to remain in the water until they are placed in the testing machine, except in the case of twenty-four-hour tests.

(6) Neat twenty-four-hour tests shall not show less than 125 pounds per square inch. Neat seven-day tests shall not show less than 400 pounds per square inch. Neat twenty-eight-day tests shall not show less than 500 pounds per square inch, and should show at least 10 per cent. increase above the seven-day test.

12. Sand Test.—Owing to insufficient data, the Committee is not prepared to specify a sand test.

13. Specific Gravity.—The specific gravity, determined upon dried cement which has passed through a No. 100 sieve, shall not be less than 3.10 nor more than 3.30. The specific gravity can be conveniently and accurately determined by the use of Le Chatelier's apparatus as recommended by the Committee on uniform tests of cements.

14. Chemical.—Chemical analyses should show not more than 5 per cent. of magnesia, nor more than 1.75 per cent. of sulphuric anhydride.

15. Uniformity.—If in the tests of any given brand of cement any sudden, irregular or wide variation from its normal action is found, it should be withheld from use until more extended tests shall have demonstrated its reliability.

NATURAL CEMENT.

NOTE—Only those sections of the natural cement specifications which differ from those of the Portland cement are printed here. To make these specifications complete, supply the missing numbers from the preceding.

1. Definition.—Natural cement is a product formed of calcinated limestone containing clay and carbonate of magnesia reduced to a fine powder.

3. Weight.—One barrel shall contain not less than 300 pounds of cement. (West of the Allegheny Mountains this may be 265 pounds.) Three paper sacks or two jute sacks of cement shall be equivalent in weight to one barrel.

8. Fineness.—Not less than 80 per cent. of the cement tested shall pass through a No. 100 standard sieve.

9. Set. (1) Initial set shall not occur in less than twenty (20) minutes.

(2) Final set shall not occur in less than forty-five (45) minutes nor more than four (4) hours.

(6) The amount of water required to make a paste of normal consistency varies with different cements, but will be found to be approximately 30 per cent. of the weight of the cement. It should have a temperature of 70 degrees Fahrenheit.

11. Tensile Strength.—(1) The briquette used in testing shall be formed in molds of the size and form now in customary use and recommended by the American Society of Engineers, the stress to be applied at a uniform rate of 400 pounds per minute until fractured.

(6) Neat twenty-four-hour tests shall not show less than 60 pounds per square inch. Neat seven-day tests shall not show less

than 100 pounds per square inch. Neat twenty-eight-day tests shall not show less than 150 pounds per square inch, nor less than 25 per cent. above the seven-day test.

13. Specific Gravity.—The specific gravity, determined upon dried cement which has passed through a No. 100 sieve, shall not be less than 2.50 nor more than 2.80. The specific gravity can be conveniently and accurately determined by the use of Le Chatelier's apparatus as recommended by the Committee on uniform tests of cements.

PORTLAND CEMENT CONCRETE.

The following Specifications for Concrete were not acted upon by the Convention for lack of time, but are considered of such importance as to justify publication in this form:

Cement.—Cement shall be Portland, either American or foreign, which will meet the requirements of the standard specifications.

Sand.—Sand shall be clean, sharp and coarse, but preferably of grains varying in size. It shall be free from clay, loam, sticks and other impurities.

Stone.—Stone shall be sound, hard and durable, crushed to sizes not exceeding two inches in any direction and freed from dust by screening.

Gravel.—Gravel shall be composed of clean pebbles of hard and durable stone, of sizes not exceeding two inches in diameter, free from clay and other impurities except sand. When containing sand in any considerable quantity, the amount per unit of volume of gravel shall be determined accurately to admit of the proper proportion of sand being maintained in the concrete mixture.

Water.—Water shall be clean and reasonably clear, free from sulphuric acid or strong alkalies.

Mixing by Hand. (1) Tight platforms shall be provided of sufficient size to accommodate men and materials for the progressive and rapid mixing of at least two batches of concrete at the same time. Batches shall not exceed one cubic yard each, and smaller batches are preferable, based upon a multiple of the number of sacks to the barrel.

(2) Spread the sand evenly upon the platform, then the cement upon the sand, and mix thoroughly until of an even color. Add all the water necessary to make a thin mortar and spread again; add the gravel if used, and finally the broken stone, both of which, if dry, should first be thoroughly wet down. Turn the mass with shovels or hoes until thoroughly incorporated and all the gravel and stone is covered with mortar; this will probably require the mass to be turned four times.

(3) Another approved method, which may be permitted at the option of the engineer in charge, is to spread the sand, then the cement, then the gravel or broken stone; add water and mix thoroughly as above.

Mixing by Machine.—A machine mixer shall be used wherever the volume of work will justify the expense of installing the plant. The necessary requirements for the machine will be that a precise and

regular proportioning of materials can be controlled and the product delivered be of the required consistency and thoroughly mixed.

Consistency.—The concrete shall be of such consistency that when dumped in place it will not require much tamping. It shall be spaded down and tamped sufficiently to level off, and will then quake freely, like jelly.

Course.—(1) Each course should be left somewhat rough to insure bonding with the next course above; and if it be already set, shall be thoroughly cleaned and dampened before the next course is placed upon it. The plane of courses shall be as nearly as possible at right angles to the line of pressure.

(2) An uncompleted course shall be left with a vertical joint where the work is stopped.

(3) The work should be carried up in sections of convenient length and completed without intermission.

Expansion Joints.—(1) In exposed work expansion joints shall be provided at intervals of thirty to fifty feet. A temporary vertical form or partition of plank shall be set up and the section behind completed as though it were the end of the structure. The partition will be removed when the next section is begun and the new concrete placed against the old without mortar flushing. Locks shall be provided if directed or called for by the plans.

(2) In reinforced or steel concrete the length of these sections may be materially increased at the option of the engineer.

Time.—Concrete shall be placed immediately after mixing and any having an initial set shall be rejected.

Facing.—About one inch of mortar of the same proportions as used in the concrete may be placed next to the forms, immediately in advance of the concrete, or a shovel facing made, at the option of the engineer in charge.

Forms.—(1) Forms shall be substantial and unyielding, properly braced or tied together by means of wire or rods.

(2) The material used shall be of dressed lumber, secured to the studding or uprights in horizontal lines.

(3) Planking once used in forms shall be cleaned before being used again.

(4) The forms must not be removed within forty-eight hours after all the concrete in that section has been placed. In freezing weather they must remain until the concrete has had a sufficient time to become thoroughly set.

(5) In dry but not freezing weather, the forms shall be drenched with water before the concrete is placed against them.

(6) For backings, undressed lumber may be used for forms.

Finishing.—(1) After the forms are removed, any small cavities or openings in the concrete shall be neatly filled with mortar if necessary. Any ridges due to cracks or joints in the lumber shall be rubbed down; the entire face shall then be washed with a thin grout of the consistency of whitewash, mixed in the proportion of one part of cement to two parts of sand. The wash should be applied with a brush.

(2) The tops of bridge seats, pedestals, copings, wing walls, etc., when not finished with natural stone coping, shall be finished

with a smooth surface composed of one part cement and two parts of granite, or other suitable screenings, or sand applied in a layer 1 to 1½ inches thick. This must be put in place with the last course of concrete.

(3) In arch tops, a thin coat of mortar or grout shall be applied over the top to thoroughly seal the pores.

Proportioning.

STRUCTURE.	PARTS BY VOLUME			
	Cement.	Sand.	Gravel.	Broken Stone.

The proportion of the materials in the concrete shall be as specifically called for by the contract, or as set forth herein, upon the lines left for that purpose; the volume of cement to be based upon the actual cubic contents of one barrel of specified weight.

H. G. KELLEY, Chief Engineer, Minneapolis & St. Louis Railway, Minneapolis, Minn., *Chairman;*

W. L. BRECKENRIDGE, Chief Engineer, Chicago, Burlington & Quincy Railroad, Chicago, Ill., *Vice-Chairman;*

E. C. BROWN, Engineer Maintenance of Way, Union Railroad, Port Perry, Pa.;

M. W. COOLEY, Consulting Engineer, Boston, Mass.;

JOHN DEAN, Consulting Engineer, St. Louis, Mo.;

C. F. W. FELT, Chief Engineer, Gulf, Colorado & Santa Fe Railway, Galveston, Tex.;

W. E. HOYT, Consulting Engineer, Rochester, N. Y.;

C. LEWIS, Civil Engineer, New York, N. Y.;

G. F. SWAIN, Professor of Civil Engineering, Massachusetts Institute of Technology, Boston, Mass.,

Committee.

SPECIFICATIONS FOR CONCRETE SIDEWALKS.

The following represents a good specification form for sidewalk construction as prepared by the writer:

Estimate No..... No. of Street.....
Ordinance Page..... No. of Letting.....

SPECIFICATIONS.

For Improving .....
From .....
To .....
With ..... Sidewalk requiring approximately .....square feet.

Requirements.—All sidewalks shall be —— feet, —— inches (— ft. —— in.) in width, the top of said walks when complete to be at the grade established by the engineer, with a slope of one-fourth inch to the foot toward the center of the street. All walks shall be laid with a space of ———— inches between the inner edge of the walk and the lot line, except by special permit from the (.....).
Proper authority.

Grading.—All cutting and filling necessary to bring the foundation to subgrade, as given by the engineer, must be done by the contractor. Wherever the soil is clay, peat or black mold, it must be removed to a depth of ten and one-half (10½) inches below the finished grade and cinders, sand or gravel filled in and thoroughly packed, rammed or rolled solid to make a foundation six (6) inches thick. All foundations must be brought to a subgrade four and one-quarter (4¼) inches below finished grade and rammed solid before laying the concrete. Soft and spongy places must be entirely removed and sand filled and rammed in the place.

Concrete.—On the foundation thus prepared shall be spread a layer of concrete, which shall be three and one-half (3½) inches in thickness, after being thoroughly compacted. The concrete shall be composed of one part of the best quality of Portland cement, two parts clean, coarse, sharp sand, and five parts of broken stones or clean, coarse gravel, of a size not larger than will pass through a 1½ inch ring. The sand and cement shall first be thoroughly mixed dry, then water added and the mortar mixed, after which the stone shall be added and the whole mass again evenly mixed until every particle of stone is completely coated with mortar. The concrete shall be quickly placed in position and thoroughly rammed over its whole surface with an iron shod rammer eight inches square and weighing not less than twenty pounds.

Top Dressing.—Upon this layer of concrete, before it shall have set, shall be spread a finishing coat three-quarter (¾) inch in thickness, composed of one part of the best Portland cement and one and one-half parts torpedo gravel or other gravel satisfactory to the engineer: said

coat to be thoroughly troweled and floated smooth. In both foundation and surface layers of concrete, transverse joints shall be cut at five foot intervals along the walk to allow for expansion and contraction and to more easily provide for any possible settlement or heaving. The surface shall not be dusted with dry cement at any time. Bevel all edges of the blocks. Sprinkle the surface two or three times each day for a week and protect it from the hot sun during the same period.

Drainage.—Where the engineer may think it necessary, the contractor shall lay two or four inch tile drains from the subfoundation to the nearest catchbasin or open ditch, to carry away any water which may collect in the subfoundation.

Cleaning Up.—After the walk has been completed, the contractor shall remove all debris, waste material and excavated earth from the street and leave the parkways in good condition.

The undersigned hereby certifies that he has read the foregoing specifications, and that the proposal for the work is based on the conditions and requirements embodied therein, and should the contract be awarded to him, he agrees to execute the work in strict accordance herewith.

Name .....

Residence .....

The following sets of specifications for concrete sidewalk are given here for further comparison with the preceding form.

The specifications in use in Chicago, Ill., are as follows:

CITY OF CHICAGO SPECIFICATIONS FOR CONCRETE SIDEWALKS.

All cutting and filling necessary to bring the foundation to sub-grade, as given by the engineer in charge of the work, must be done by the contractor. When necessary the foundation must be consolidated by wetting, rolling or ramming to give it proper stability. Soft and spongy places not affording a firm foundation must be dug out and re-filled with sand or gravel, and well compacted by ramming, and foundation brought to within four and one-half (4½) inches of the grade.

On the surface thus prepared shall be placed a layer of hydraulic cement concrete for four (4) inches in thickness, composed of one part best Portland cement, two parts best clean, coarse, sharp sand. After mixing dry, five parts of broken stone, of a size not larger than two and one-half (2½) inches in dimensions, shall be added and then water added in just sufficient quantity as will give a surplus of moisture when rammed.

The second layer or finishing coat, one-half (½) inch in thickness, to be made of one part best imported Portland cement and one part torpedo gravel to be used before the first layer has set.

The undersigned hereby certifies that he has read the foregoing specifications, and that his proposal for the work is based on the conditions and requirements embodied therein, and should the contract be awarded to him he agrees to execute the work in strict accordance herewith.

Name ..... Residence .....

The specifications in use in Columbus, Ohio, are as follows:

SPECIFICATIONS FOR IMPROVING SIDEWALKS WITH ARTIFICIAL STONE, IN THE CITY OF COLUMBUS, OHIO.

1. By "artificial stone" herein specified is meant a composition of Portland cement, sand, and fragments of natural stone.

2. By "sub-grade" is meant the ground surface upon which the pavement foundation is laid.

3. By "sub-drainage" is meant a line of three (3) inch diameter, round, butt-jointed, hard-burned drain tile, laid in a trench one foot wide and one foot deep below sub-grade, parallel to the direction of the sidewalk, and true for line and grade, the trench to be filled to the sub-grade with broken stone, crushed or screened gravel as herein specified for concrete, which shall be compacted by ramming, care being used not to disturb the drain tile. The out-let or discharge for the drain to be by connection with the street inlets, or, in the absence of street inlets, by such other arrangement as the Engineer may prescribe.

4. By "cinders" is meant clean, sharp, soft coal cinders, free from ashes and clinkers.

5. By "screened gravel" is meant clean sharp bank gravel, free from loam or vegetable matter, so screened that no fragment will measure more than ..... inches on its longest diameter, and not enough of these to make the quantity of fine gravel so small as to prevent its packing readily under the roller. The question as to whether the material is too fine or too coarse, and as to its general suitableness for the purpose for which it is intended, shall rest entirely with the engineer.

6. By "sand" is meant clean, sharp bank sand, free from loam, vegetable matter, or fragments of coal, and screened free from pebbles.

7. By "broken stone" is meant granite, trap-rock, hard limestone, or other hard durable stone, so broken or crushed that no fragment will measure more than one and one-half (1½) inches on its longest diameter, nor less than one-half (½) inch on its shortest diameter, to be entirely free from dust or dirt.

8. By "cement" is meant German or American Portland Cement. The cement to be received on the work in unbroken packages, to be fresh, free from lumps, and subject to inspection by the Engineer in every case.

9. By "crushed gravel" is meant clean sharp bank gravel, free from loam or vegetable matter, so broken or crushed that no fragment will measuring more than one and one-half (1½) inches on its longest diameter.

10. By "paving" is meant the laying of an artificial stone pavement where the sidewalk has not been previously paved with artificial stone.

11. By "repairing" is meant restoring in part artificial stone sidewalks previously laid.

PAVING.

Sub-grade.—The sub-grade will be brought to an even compact surface uniformly twelve (12) inches below the proposed surface of the finished pavement. Soft or spongy earth, vegetable or other perishable matter will be removed, and the space filled with gravel or broken stone thoroughly compacted by ramming.

Sub-drainage.—Sub-drainage will be put in where the Engineer directs.

Foundation.—Upon the sub-grade thus prepared will be spread a bed of cinders, crushed or screened gravel, in sufficient quantity to insure a uniform

depth of eight (8) inches after being compacted by wetting and rolling or ramming, the surface of the cinder, crushed or screened gravel, foundation to be even, parallel to the proposed pavement surface and four (4) inches below it.

Concrete. —Upon the foundation will be placed a layer of concrete. This concrete will be spread and rammed to an even surface, parallel to, and one (1) inch below the proposed pavement surface before any set in the mortar can occur; the concrete must be composed of one (1) part, by measure, of cement, two (2) parts sand, and four (4) parts broken stone, crushed or screened gravel. The cement and sand will be thoroughly mixed dry and then made into mortar with the least possible amount of water. The broken stone, drenched with water, will then be incorporated with the mortar. The concrete will be thoroughly mixed, the mixing to continue until each fragment of stone is completely coated with mortar, spread and rammed until free mortar appears on the surface, which shall be smooth and one (1) inch below the pavement grade. The whole operation of mixing and laying the concrete will be performed as expeditiously as possible by a sufficient number of skilled men. Platforms or boxes will be used in every case for the concrete bed.

Wearing Surface. —The wearing surface will be composed of one (1) part, by measure, of cement, and one (1) part sand, thoroughly mixed dry, with the addition of sufficient clean water to form a stiff mortar. This mortar will be evenly spread upon the concrete base before any set can occur in the mortar and before the concrete has become dry. The mortar, as soon as spread, will be floated and troweled to a true smooth surface at the sidewalk grade, neatly and accurately fitted around all openings or immovable objects in the sidewalk and along the outside margin. Boxes will be used in every case for the mortar bed.

Blocking.—The surface of the pavement, before the mortar sets, will be cut into blocks with a wedge-shaped tool, leaving a clean groove five-eighths (⅝) of an inch deep, one-eighth (⅛) of an inch wide at the bottom, and one quarter (¼) of an inch at the top, the cut to be finished with a T shaped tool, the object of this being to make firm, smooth, and slightly round the top edges of the groove. The blocks will be made with straight sides, generally rectangular, measuring, ordinarily, not less than four (4) nor more than six (6) feet on a side. The design of the blocking to be subject to special direction by the Engineer in each case. The blocking for driveways will be done by cutting and finishing as before described, except that the grooves will be one-fourth (¼) of an inch at the bottom and one-half of an inch (½) at the top or pavement surface, the design to be furnished by the Engineer, and will generally be in strips six (6) inches wide across the driveway (along the pavement) or in six (6) inch squares.

Grade of Sidewalk. –The full-width sidewalk, at its junction with the curb, will be, unless otherwise ordered by the Engineer, one-half (½) inch above the curbing, with a neat bevel and a slight lap. The slope of the full width pavement will be three-eighth (⅜) of an inch per foot, up from the curb to the lot line, unless otherwise directed by the Engineer. The alignment, elevation, and slope of pavements less than the full width of the sidewalk will be subject to special direction from the Engineer in each case.

Driveways.—The construction of driveways will be with the same materials and in the same manner as specified for "Paving" except that the gravel or

cinder foundation will be five (5) inches thick, the concrete five (5) inches thick, and the top surface two (2 inches thick.

Repairing.—In repairing, such portions of the existing artificial pavement as ordered by the Engineer shall be removed and new work substituted, laid in precisely the same manner as herein specified under "Paving".

Sidewalk Gutters or Cross Drains.—Only upon special permission by the Engineer will sidewalk gutters or cross drains be allowed.

When surface drains are permitted they will be formed in the artificial stone pavement of such width, depth, and shape as the Engineer specially directs.

Where cross-drains are permitted below the surface they will be laid with vitrified stoneware socket pipe, of such bore as the Engineer directs, with joints cemented with mortar before specified.

All openings in the curbing for outlets into the gutter for cross-drains will be skillfully made by a competent stone cutter, under the direction of the Engineer, and any curbstone defaced or broken in this operation will be replaced.

CEMENT.

Portland Cement must satisfy the following requirements:

1. The cement shall stand a minimum tensile strain of 400 pounds to one square inch section (neat briquettes 1 day in air and 6 days in water.)

2. The cement shall stand a minimum tensile strain of 125 lbs. to one square inch section, 3 parts sand to 1 cement, (1 day in air 6 days in water.)

Natural Cements must stand the following tests:

Neat briquettes must develop after seven days a tensile strain of 100 lbs. per sq. in., 4 weeks 150 lbs. Briquettes made of one part cement and one part sand must stand at the end of seven days a tensile strain of 50 lbs. per sq. in., at the end of 4 weeks 80 lbs. per sq.in.

The specifications in use in Peoria, Ill., are as follows:

SPECIFICATIONS FOR CEMENT WALKS AS USED BY DEPARTMENT OF PUBLIC WORKS, PEORIA, ILLINOIS.

1. **Location.**—The sidewalk herein specified shall be constructed on..... ..... Street, in front of Lot..... Block ..... of ....Addition.

2. **Width and Slope.**—The walk shall be ..... feet wide, with a transverse slope of one-third of an inch per foot toward the gutter, and shall be laid to the lines and grades given by the City Engineer.

GRADING.

3. **Sub-grade.**— The ground shall be excavated to a depth of twelve (12) inches below the surface of finished walk, and the surface of the sub-grade shall be thoroughly and evenly tamped with an eighty (80) pound tamper.

4. **Excavation.**—In places where cutting is necessary to bring the walk to the required grade, no plow shall be used below a line three (3) inches above the surface to which the sub-grade is to be graded. The remaining three (3) inches to be carefully dressed off with picks or other hand tools.

5. **Fill.**—Wherever fill is required, it will be made with any suitable material excavated from this improvement. Should such suitable excavated material not be sufficient to make the necessary fills, the Contractor will be required to procure material acceptable to the Engineer. All filling shall be made in uniform layers not to exceed four (4) inches in depth, and each layer shall be thoroughly flooded and rolled, or tamped as may be directed to insure a solid bed.

6. **Removing Soft Materials.**—All mud and other soft or spongy material or any material that cannot be made solid and compact, shall be removed and the places refilled with gravel.

7. **Flooding Sub-grade.**—When considered necessary to procure a compact and solid sub-grade, the ground, before being rolled, shall be thoroughly flooded with water in such a manner as the Engineer may direct.

FOUNDATION.

8. **Cinders or Sand.**—Upon the sub-grade prepared as above will be laid a foundation course eight (8) inches thick of sand or cinders, which shall be flooded and thoroughly rolled or tamped in such a manner as to procure a compact and solid foundation.

9. **Concrete.**—Upon this sand or cinder foundation a concrete foundation three (3) inches thick after being compressed, shall be laid.

10. **Proportions.**—The concrete shall be composed of one (1) part, by bulk, of best imported Portland cement, three (3) parts, by bulk, of clean, sharp sand, and five (5) parts, by bulk, of broken stone or gravel.

11. **Intention of Proportions.**—The proportions herein specified are intended to produce a concrete in which the mortar will fill all the voids, and the proportions will be so adjusted that when rammed in place free mortar will flush to the surface.

MIXING AND SPREADING CONCRETE.

12. **Mixing Sand and Cement.**—The sand and cement shall be thoroughly mixed dry in a tight mortar box and then made into a mortar of the proper consistency and thoroughly worked over with hoes.

13. **Additions of Stone.**—Broken stone or gravel thoroughly cleaned of dirt, drenched with water, but containing no loose water in the heap, shall then be added to the mortar in the proper proportion. The concrete will then be turned and mixed until mortar adheres to each fragment.

14. **Consistency of Concrete.**—The concrete thus mixed shall have such a consistency that when rammed the mass will not shake like jelly, but will, when struck, compact within the area of the face of the rammer without displacing the material laterally.

15. **Immediate Use of.**—The concrete thus prepared shall be immediately placed in the work. It shall be spread and thoroughly compacted by ramming until free mortar appears on the surface.

16. **Mixing and Laying.**—The whole operation of mixing and laying each batch of concrete shall be performed in an expeditious and workmanlike manner, and be thoroughly completed before the cement has begun to set.

17. **Re-tempering.** — No re-tempering of concrete will be permitted, and concrete in which the mortar has begun to set will be rejected.

18. **Conform to Grade.**—The upper surface of the concrete shall be made to conform perfectly to the grade of the sidewalk to be laid.

19. **Minimum Temperature.**—No concrete shall be laid when the tem perature at any time during the day or night falls below thirty-five (35) degrees Fahrenheit.

WEARING SURFACE.

20. **Composition.** —Upon the concrete base there shall be spread a finish coat, or wearing surface, one (1) inch thick composed of one (1) part cement, ¾ of one part crushed quartzite rock, and ¾ of one part clean, sharp sand.

21. **Spreading.** —This wearing surface shall be placed on the concrete as soon as the same is tamped and before it has begun to set. It must be quickly and evenly spread, and will then be floated and troweled to a true smooth surface conforming to the grade given.

22. **Blocking.** — The surface of the sidewalk before the mortar sets will be cut into blocks, with a wedge-shaped tool, leaving a clean groove one-half an inch deep, one-eighth of an inch wide at the bottom, and one-quarter of an inch wide at the top. The blocks will be rectangular in shape, with straight sides, measuring not less than four nor more than six feet on a side.

23. **Walk at Curbing.**—When the walk extends to the curb line it shall be one-half (½) inch above the curbing for the full width, unless otherwise ordered by the Engineer, with a neat bevel and a slight lap at its junction with the curbing

REQUIREMENTS OF MATERIALS.

CEMENT.

24. **Kind.** —All cement used shall be the best imported Portland cement. It will be subjected to rigid inspection, and that rejected shall be immediately removed by the Contractor.

25. Cement for Inspection and Tests.—The contractor must submit the cement for inspection and testing at least ten (10) days before using, and such inspection and tests will be made only from samples obtained by the Inspector from cement delivered on the work. The inspector shall be notified of each delivery of cement. All cement must stand the following tests:

26. Checking and Cracking.—Two cakes, three inches in diameter and one-half inch thick, with thin edges, will be made. One of these cakes as soon as set will be placed in water and examined from day to day. If the cake exhibits checks, cracks or contortions, the cement will be rejected. The other cake described will be used for setting and color tests.

27. Beginning of Set.—The time will be noted when the cake has become hard enough to sustain a wire one-twelfth inch in diameter loaded with one-fourth pound. When the wire is sustained, the cement has begun to set, and this time shall not be less than forty-five (45) minutes.

28. End of Set.—When the cake will sustain a wire one twenty-fourth inch in diameter loaded with one pound, the set is complete, and this time must not be less than two (2) hours nor more than six (6) hours.

29. Color.—The cake used for setting test will be preserved, and when examined from day to day must be of uniform color, exhibiting no blotches or discolorations.

30. Fineness.—The cement must be evenly ground, and when tested with the following standard sieves, must pass at least the following percentages. No. 50 sieve, having 50 meshes per lineal inch, 98 per cent; No. 74 sieve, having 74 meshes per lineal inch, 94 per cent; No. 100 sieve, having 100 meshes per lineal inch, 90 per cent. The diameter of wire for the sieves being respectively: For No. 50 sieve, No. 35 Stub's wire gauge; For No. 74 sieve, No. 37 Stub's wire gauge; For No. 100 sieve, No. 40, Stub's wire gauge.

31. Mixing Test Cement.—All cement for test briquettes, will be mixed with barely sufficient water to make a stiff mortar. The neat briquettes to be pressed into the molds by hand and the sand briquettes to be compacted by light tapping.

32. Strength.—The required tensile strength per square inch shall be as follows:

Neat cement:

One day—till set in air, remainder time in water..... 150 lbs.
One week—one day in air, six days in water .....400 lbs.

Cement one part, and sand three parts:

One week—one day in air, six days in water..... 140 lbs.

33. Covering Briquettes.—Briquettes for seven (7) day tests will be covered for the first twenty-four (24) hours with a damp cloth.

SAND.

34. Sand for Concrete.—The sand for concrete shall be clean, sharp silicious sand. It shall be free from clay or other mineral impurities, loam or organic matter, and shall be thoroughly screened.

35. Sand for Finish Coat.—The sand for cement tests, and for the finish coat of the walk, will be crushed quartzite of such fineness that all will pass a sieve of 10 meshes per lineal inch, and none of it a sieve of 50 meshes per lineal inch.

WATER.

36. Requirements. —All water must be practically clean and pure.

STONE.

37. Quality.—The stone for concrete shall be of such hardness and durability as shall meet the approval of the Commissioner and Engineer.

38. Platforms for Stone.—The broken stone when delivered along the line of work shall be deposited on platforms for that purpose.

39. Size.—The broken stone shall range in size from one-fourth (¼) of an inch, to one and one-half (1½) inches in the greatest dimension. It shall be free from mud, dirt, dust, loam or other objectionable material.

39. Screening.— The broken stone shall be screened, when necessary, on a one-fourth (¼) inch screen, to eliminate all dust and small particles, and shall be thoroughly drenched with water immediately before being used in the concrete.

GRAVEL.

40. Size. —The gravel shall consist of particles ranging in size from one-fourth (¼) of an inch to one (1) inch in the greatest dimension.

41. Washed and Screened. —It shall be clean washed gravel free from loam, vegetable matter, clay, silty sand or other foreign matter and shall be screened on a one-fourth (¼) inch screen.

42. Platforms for Gravel. —When delivered along the line of the work, the gravel shall be deposited on platforms made for that purpose.

CINDERS.

43. Requirements. —The cinders shall be clean, sharp, soft-coal cinders free from ashes and clinkers.

SPECIFICATIONS FOR HEAVY CONCRETE.

For heavy concrete work, the specifications of Major W. L. Marshall, corps of engineers, for the locks in the Illinois and Mississippi canal in Illinois will serve as a fair example of United States Engineers' practice. Sections II and III only are quoted as being directly applicable to the concrete work.

II. PROPORTIONS AND MIXING OF CONCRETE.

II. Proportions and ingredients are measured by volume, and the number of cubic feet given below represent the quantities to be used for each charge of concrete put into the mixer,

Portland cement concrete shall in general consist of:

Portland cement	1 part = 5 cu. ft.	= 5 sacks
Gravel	4 parts = 20 cu. ft.	
Broken stone	4 parts = 20 cu. ft.	

For the wall supporting the upper gate and in the vicinity of the quoins the concrete shall consist of:

Portland cement	6 cu. ft.	= 6 sacks
Gravel	20 cu. ft.	
Broken stone	20 cu. ft.	

Natural cement concrete shall consist of:

Natural cement	2 parts = 8 cu. ft.	= 4 sacks
Gravel	5 parts = 20 cu. ft.	
Broken stone	5 parts = 20 cu. ft.	

Facing material shall consist of, by volume:

Portland cement	1 part
Torpedo sand passing No. 5 sieve	3 parts

12. The piles of gravel and broken stone shall be kept thoroughly sprinkled with water to clean surface of dust and to prevent absorption by the dry stone of the water used in mixing the concrete.

13. When delivered in bags each bag of cement shall be emptied directly into the charging box, as the division of a barrel of cement into several bags diminishes the chances of injurious effect of a defective barrel, and hence the usual requirements of drawing charges from a mixture of five or more barrels may be dispensed with. When delivered in barrels this latter requirement will be observed.

14. All bags and sacks shall be carefully preserved for return to the dealers furnishing cement, in order to secure to the United States the rebate thereon, to be deducted from subsequent bills for cement.

15. The proper measures of ingredients shall be emptied into the charging box in the following order: 1st, gravel; 2nd, cement; 3rd, broken stone; 4th, water.

16. Enough water shall be added to make the concrete cohere after a thorough mixing. A greater degree of plasticity than that possessed by damp sand is required and the object is to have the consistency such that a thorough ramming will bring water to the surface. The mass of concrete should not quake on ramming; incipient quaking marks the limit, and any excess of water in one charge may be corrected by making the next charge a little dryer. The proper amount of water can be determined only by exper-

ience, and must be varied from time to time to suit the conditions of the weather and the ingredients. It is very important that Portland cement shall have sufficient water for its complete hydration. Natural cement requires less water for hydration than Portland.

17. The contents of the charging box shall be dumped immediately into the cubical mixer, which shall be revolved for not less than two minutes at a rate not exceeding nine revolutions per minute. The product is improved by longer mixing, and all the time less than period required for initial set, available between deliveries required at the forms should be utilized for extra turns to the mixer. The facing material shall be mixed by hand, and a very small gang will be able to keep the forms supplied, as for a facing of a uniform thickness of two inches, about 70 cubic yards only will be required for a lock, or about 3½ cubic yards to each section. A close watch must be kept of the quantity used, and the above limit must not be exceeded.

III. DEPOSITING AND RAMMING CONCRETE.

18. Each lock wall shall be built in sections, averaging about 20 feet in length, making 10 sections to each wall. The planes of division between sections shall be at right angles to the axis of the lock, and are indicated on drawings furnished from this office.

19. Each section shall be a monolithic mass of concrete built continuously from the bottom to completion without horizontal joints. The sections shall be filled with horizontal layers about six inches thick, each layer to be deposited before the "initial" set of the previously deposited layer.

20. The vertical planes of division between sections shall be made by transverse bulkheads built in the forms and at each bulkhead a dovetail or recess shall be made for the interlocking of adjacent sections, the dovetails reaching from foundation to one foot below the coping of the sections.

21. Alternate sections shall be built first, then the bulkheads shall be removed and the remaining sections filled with concrete.

22. Before beginning a section, its foundation shall be swept clean with wire brooms and covered with a wet layer one inch thick of 1 to 1 cement mortar to make a close joint between the wall and the foundation.

23. The walls of the wooden forms shall be kept well wet during the progress of the concrete work to prevent their absorption of water from the newly placed concrete.

24. The lowest step or thickest part of the lock walls shall consist of not less than two (2) feet of Portland cement concrete next to the face of the wall and a backing of Natural cement concrete. All other walls or parts of walls shall be of Portland cement concrete.

25. The exposed faces and copings of all walls shall consist of Portland cement and torpedo sand 1 to 3. The thickness of facings shall not exceed 1½ inches, nor be less than ¾ inch.

26. The facing and backing must go on simultaneously in the same horizontal layers. In order to gauge the thickness of the facing accurately, a light board or diaphragm of thin metal with convenient handles shall be set on edge parallel to and 1½ inches from the front wall of the forms. The facing material shall be deposited in the space between this board and the form. The concrete of the backing shall then be deposited and spread against the back of this board, which may then be withdrawn and the whole mass thoroughly rammed so as to bond the facing and backing by destroying the surface of demarcation between them, but no stone must be forced

nearer to the front wall of the form than ¾ inch. No attempt shall be made to secure a definite surface between the Portland and Natural cement concrete in the lowest step of the lock walls, but they shall be thoroughly bonded, blended and interlocked one into the other by long lap or splice joints in every layer deposited.

27. When the top surface of the coping is reached it shall be finished after ramming by cutting off the excess with a straight edge and rubbed smooth and hard with a float by skilled sidewalk finishers. The wet finishing coat shall be of 1 to 3 mortar with torpedo sand, and shall be as thin as possible without exposing the stone or gravel of the concrete below. The coping of lock walls shall be slightly crowned in the center.

28. The facing and coping shall show a smooth dense surface without pits or irregularities. This is most likely to be secured by thorough and systematic ramming.

29. Concrete shall not be laid in water nor exposed to the action of water until thoroughly set. Concrete or mortar shall not be made when the temperature is lower than 35 deg. fahr. in the shade, nor when rain is falling on it. All concrete work shall cease November 20th, and not be resumed before April 1st. Forms and molds must be left in position for not less than four days after concrete is deposited. Freshly deposited concrete shall be protected from the direct rays of the sun and from wind by boards or tarpaulins, and as soon as a section of wall is completed the exposed coping must be covered with a thick layer of sand and the whole mass of wall must be kept sprinkled until the concrete is thoroughly set.

For the construction of the proposed concrete dam in the Scioto river for the water supply system of Columbus, Ohio, the following specifications were prepared by the City Engineer, Mr. Julian Griggs.

SPECIFICATIONS FOR THE SCIOTO RIVER DAM.

37. *Concrete.*—This will be composed of one part by measure of cement, loose measure, two parts loose sand, not compacted, and four parts of broken stone. All concrete shall be made only in mechanical mixers, either cubical steel or iron boxes, sometimes called malaxators, measuring five feet on the edge, and capable of mixing two-barrel batches of concrete at one time, or continuous rotary mixers of approved design. These mixers will be supplied with independent friction clutches for each mixer, giving independent action. A sufficient number of these must be provided to turn out the average quantity of 200 cubic yards daily, with an engine capable of turning them simultaneously when loaded. The equipment for manufacture of concrete will comprise all that is necessary for storing a sufficient quantity of material and for handling and accurately measuring the same when placed in the mixers. Material will be placed in the mixers in the order directed by the engineer which will in his judgment give best results, the proportion of water being so regulated that the concrete can be thoroughly compacted and will then show merely a film of moisture upon the surface. Each batch of concrete will be given 28 revolutions, or as many as may be required to produce the most thorough mixing, at a rate not exceeding 7 revolutions per minute, not more than two barrels of cement, with the proper proportions of sand and stone, being mixed at one time. Provision for rapid transportation of the concrete must be made so that it shall be in place in the finished work before the initial set commences. For distributing and ramming the concrete in place after delivery, a sufficient force of rammers and shovelers shall be maintained for each mixer in operation to handle the concrete rapidly and ram it thoroughly. All concrete must be thoroughly compacted by ramming in layers not exceeding six inches in thickness before ramming. The rammers will be of iron or steel, with a flat rectangular face six inches square and weighing not less than twenty pounds.

38. *Facings.*—The exposed surfaces of concrete work shall be faced with a mortar composed of one part of standard Silica cement which shall comply with these specifications in every particular, and two parts of sand, to which shall be added one per cent. by weight each of pulverized alum and potash soap, the soap to be weighed before being dissolved in water and the alum to be thoroughly mixed dry with the cement and sand. The amount of water to be used shall be barely sufficient to flush slightly to the surface after hard ramming.

The facings of this material shall be not less than three inches thick and shall be incorporated with the body concrete in the following manner: As each batch of concrete is placed next the forms a loose plank shall be put next the form of requisite thickness, so that when removed as soon as concrete is placed and lightly tamped the space left may be filled with the facing material, and the whole thoroughly rammed together at one and the same time. This ramming shall be done with such extreme care as to insure the absence of all holes or the bridging of the material, leaving the surface absolutely smooth and uniform when the forms are removed. Necessary deviations from this method may be adopted on the approval of the Chief Engineer.

39. Large Stone.—The incorporation into the concrete of clean, hard, sound stones, roughly scabbled and of all sizes that may be conveniently handled over 50 lbs. weight, will be permitted, provided the stones be separated by a minimum thickness of 4 inches of concrete, and be thoroughly imbedded in the concrete on every side. Such stones must be thoroughly scrubbed clean before being placed in the work and shall be wetted immediately before setting in position. At least 30 per cent. of the entire mass may consist of stones so embodied in the work. Any stones considered unsound or unsuitable by the engineer shall be immediately removed.

40. Ramming. —The rammers for the facing shall be of iron or steel with flat rectangular faces 1¼ inches by 4 inches. They shall be 5 inches long with solid steel handles. The operation of ramming must give a thoroughly compacted dense, artificial stone of high specific gravity. When deficiency of moisture is indicated after ramming is completed, it will be supplied by sprinkling with a fine spray of water. All exposed surfaces of unfinished work will be kept constantly moist by sprinkling at short intervals. For this purpose not less than one large watering pot for each mixer will be kept in constant service, and as many more as may be required.

41. Water Tank.—The contractor will be required to provide a tank of 10,000 gallons capacity, at a height of 50 feet above top of dam, keeping the same well filled and connected with hose for the frequent and practically continuous sprinkling of the finished work.

42. Surface to be Cleaned and Roughened.—Rock surfaces, and concrete surfaces more than twenty-four hours old, shall be mopped with a mixture of neat Portland cement mortar immediately before the application of a fresh course of concrete, and all surfaces to which mortar or concrete is applied shall be made clean from any dirt, sand, clay or foreign substances and carefully roughened by picking before the application of such mortar or concrete. Under no circumstances will any concrete be laid in water or in freezing weather.

43. Concrete Forms. —Concrete forms must be rigidly held in position so as to give accurately the exterior surface required by the plans for the work, being secured against yielding to the operation of ramming. Surfaces of planking forming exterior faces must give the true, plane surface or curved surface required for the walls, and shall be dressed to make the planks of a uniform thickness. The price bid per cubic yard for concrete in place shall include all lumber, timber, bolts and materials used in the forms for the concrete. Also all special molds for ornamental arches, outline of imitation range work on lower faces as shown by the plans and all pick facing to remove mold marks, and give the exterior face of wall the appearance of cyclopean masonry indicated on the drawings.

44. Cement. —The contractor will be required to provide a suitable building, heated when necessary, to maintain the proper temperature, for testing cement, and also the necessary labor for handling the barrels or packages and taking the samples for testing purposes. Cement must be on hand for testing in time to complete all tests before the cement is required for use in the work, which shall not be more than ten days. It is to be stored in dry, well ventilated buildings, and protected from deterioration. It may be rejected for such deterioration, after passing the required tests. Cement must be stored by carload lots for ready removal of any lot condemned. It must be stored in strong packages, well lined with paper, so as to be reasonably secure from air and moisture. Each package to be labeled with the name of the

brand and the name of the manufacturer. Any packages broken at the time of delivery may be rejected, or used as half packages at the option of the Engineer.

45. **Weight.**—Ordinarily ten per cent. of the packages in each carload lot will be selected for weighing and testing. The average net weight of all packages in each carload lot will be the average net weight of all the selected packages. The failure of any one of the selected packages to stand the required tests will be sufficient reason for the rejection of this carload lot, in the discretion of the Engineer. Rejected cement will be branded and immediately removed from the work.

46. **Fineness.**—Of Portland cement, ninety-eight per cent. (98%) by weight must pass through a cement wire sieve having 2,500 meshes per square inch, made of No. 35 wire, S. W. G., and ninety-five per cent. (95%) by weight must pass through a sieve having 10,000 meshes per square inch, and made of No. 40 wire, S. W. G.

47. **Test Briquettes.**—Test briquettes for Portland cement will be made both neat and in proportions of one cement to three of sand. Enough water only will be used to thoroughly moisten the mixture, which will be forced into the mold by pressure or tamping, so as to give as nearly as possible the density of good concrete work. The temperature of the water and of the room in which the briquettes are made and tested will not be permitted to fall below 60 degrees Fahrenheit. The sand used in preparing all briquettes shall be clean, sharp, crushed quartz, retained on a sieve of thirty meshes per lineal inch, (holes 0.022″ square) and passing through a sieve of twenty meshes per lineal inch (holes 0.033″ square.)

48. **Initial Set and Hot Water Test.**—Cement mixed neat with about 22 per cent. of water to form a stiff paste, shall not begin its initial set for forty minutes after mixing with water and after sixty minutes it must be appreciably indented by the end of a wire one-twelfth inch in diameter, loaded to weigh one-quarter pound. Cement made into thin cakes on glass plates shall not crack, scale nor warp under the following treatment: Three pats will be made and allowed to harden in moist air at from 60 to 70 degrees temperature; one of these will be subjected to water vapor at 176 degrees temperature for three hours, after which it will be immersed in hot water forty-eight hours; another will be placed in water at from 60 to 70 degrees temperature; and the third will be left in moist air.

49. **Tensile Strength.**—The tensile strength will be determined by the average strength of three briquettes of neat cement and the average strength of three briquettes of cement and sand. These will be kept in moist air until set, and then immersed in water until they are put into the clips of the testing machine, being tested wet. Briquettes prepared from neat Portland cement shall, after seven days, develop a tensile strength of not less than 450 pounds per square inch, and after 28 days not less than 550 pounds per square inch. Briquettes prepared from a mixture of one part Portland cement and three parts sand (parts by weight) shall, after seven days, develop a tensile strength of not less than 125 pounds per square inch and not less than 200 pounds per square inch after 28 days. Briquettes prepared from a mixture of one part Portland cement and three parts sand (parts by weight) and immersed, after 24 hours, in water maintained at 170 degrees Fahrenheit, shall not swell nor crack, and shall, after seven days, develop a tensile strength of not less than 150 pounds per square inch.

50. **Sand.**—Sand will be sensibly free from loam, clay, or other impurity, sharp, angular, and silicious. When used in connection with cement tests in the place of standard quartz, it must give results in each case at least equal to those obtained by the use of standard quartz. Samples of the sand proposed to be furnished shall be submitted with each bid and retained in the office of the Department of Public Improvements as a standard for comparison during the progress of the work.

51. **Broken Stone.**—Broken stone for concrete: All of the stone used in the dam must be excavated from the area covered by the site designated by the Engineer, selecting and using only such stone as is hard and durable, of a quality approved by the Engineer, and of such character as to break in approximately cubical fragments. It will be broken so that no dimensions shall be greater than one and one-half inches and must be thoroughly screened from dust and dirt, and washed if deemed necessary.

SPECIFICATIONS FOR CONCRETE ROAD FOUNDATIONS.

In order to give opportunity for comparison, the specifications for concrete foundations under streets and roads for three cities are given.

The specifications in use in Columbus, Ohio, are as follows:

Sec. 28.—CONCRETE ROAD FOUNDATION.

American Portland Cement.—Upon the sub-grade a foundation of American Portland cement concrete shall be laid to a uniform depth of six (6) inches, prepared and applied as hereinafter specified.

Sand. —The sand used in the mortar shall be clean, coarse, screened river or lake sand of approved quality.

Crushed Stone.—The material for the body of the concrete shall be composed of limestone, crushed limestone boulders, or other material, equally hard and approved by the Engineer, broken so as to pass through a two-inch ring in its largest dimensions. The material shall be free from all dust or dirt; no gravel will be used.

Cement. —The cement used will be of the best quality American Portland cement, delivered in original packages, with the brand stamped or printed upon the same.

Fineness. —It must be finely ground, so that at least 90 per cent. will pass through a sieve with 10,000 meshes per square inch.

When mixed with water and worked up into a cake it must not attain its initial set until one hour after mixing, nor its final set until after three hours.

Tensile Strength. —When mixed neat and worked up into briquettes, and exposed one day in air and six days in water, it must develop a tensile strength of 400 pounds per square inch.

When mixed with three parts by weight of standard sand to one of cement, it must develop a tensile strength of 150 pounds per square inch in seven days.

Unsoundness and Color. —Two cakes with thin edges will be made of neat cement, one will be kept under water to note changes of color; the other will be placed in boiling water, after its final set, and kept there for 12 hours; if the color changes in irregular spots during a period of ten days, or if the boiled cake shows any cracks or softness, it shall be rejected as unsound.

Packages to be Marked by Engineer.—All packages of cement must be marked by the Engineer or superintendent before being used.

Mixing.—One part by measure of cement and three parts of sand will be thoroughly mixed dry and then made into mortar with a minimum quantity of water; six parts by measure of crushed boulder, limestone or other equally hard material, having been previously saturated with water, will then be incorporated immediately with the mortar.

Size of Crushed Stone. —Each batch of concrete will be thoroughly mixed, the mixing to be continued on the board until each piece of stone is completely coated with mortar. It will then be spread and at once thoroughly compacted by ramming until free mortar appears upon the surface. The whole operation of mixing and laying each batch will be performed as expeditiously as possible and with the use of a sufficient number of skilled men. The upper surface will be made exactly parallel with the surface of

the pavement to be laid, and when in place all wheeling, working or walking on it must be prevented until it is sufficiently set, and in no case will any material be wheeled upon the foundation until 24 hours after having been put in place.

Materials must be brought upon the foundation in barrows, unless delivered upon the same from the sidewalk.

The specifications in use in Washington, D. C., are as follows:

4 **Concrete Base.** —Upon the bed (sub-grade) thus prepared there will be laid a four (4) or six (6) inch foundation of concrete, as directed, made of broken stone and gravel, sand, and natural cement in such proportions that the quantity of gravel will be equal to the volume of voids in the broken stone, and the sand and cement, mixed in the proportion of one (1) part cement and two (2) parts sand, will be 20 per cent. in excess of the volume of voids in the combined gravel and broken stone.

5. **Hydraulic Cement.** —The cement in use shall be a natural hydraulic cement, and shall conform to the current specifications for supplying such hydraulic cement to the Engineer Department of the District of Columbia. No hydraulic cement shall be used upon the work until it has been tested in the office of the Engineer Commissioner and accepted by him, the tests to extend over such length of time, not exceeding twenty-eight days, as the Engineer Commissioner may think necessary. The cement, while in storage or upon the work, while being hauled upon the work, shall be properly protected, and no cement shall be used which, in the opinion of the Engineer Commissioner, has been injured by age or exposure. The cement shall be kept by the contractor in store, under proper cover, in the city of Washington, and subject to inspection for at least ten days before it is used on the streets, and if deemed advisable by the Engineer Commissioner, twenty-eight days. Should the contractor's work be delayed by his failure to keep himself supplied with the necessary amount of approved cement, the District shall have the right to furnish him with tested cement from the stock on hand at its warehouse and charge said contractor with the cost of same at the rate of seventy-five (75) cents per barrel for each and every barrel so furnished, and collect the amount due therefor from any moneys found to be due to said contractor by the District.

6. **Sand.** —The sand used shall be clean, sharp river sand, containing both fine and coarse grains, but free from sewerage, mud, clay, mica, paper, leaves, chips, and other foreign matter, and not showing, when shaken with water and after subsidence, more than five (5) per cent., by volume, of silt.

7. **Broken Stone.** —Stone used in concrete must be hard, durable, and properly broken to a size small enough in their largest dimensions to pass through a ring two (2) inches in diameter, and none smaller than ½ inch can be used. It shall be thoroughly cleansed from all foreign substance and shall be screened and washed, if so ordered by the Engineer. Sand, detritus, or any material other than hard, angular fragments of stone will be considered foreign substances.

8. **Gravel.**—Gravel shall be clean, washed gravel, and shall not contain pebbles greater than one and one-half (1½) inches in their largest dimensions.

9. **Water.**—Water used for mortar and concrete shall be fresh and clean, free from earth, dirt, or sewerage, and shall be used in such quantity as the Engineer may direct.

10. **Platforms.** —Platforms shall be provided upon which all sand, gravel and broken stone shall be placed when brought upon the line of the work, and kept there until used.

11. **Mixing.**—Concrete may be mixed by hand labor or by machinery, but, in either manner, the thorough incorporation of the several materials required will be insisted upon. If machinery is employed for the purpose, its operation

must be subject to the direction of the Engineer Commissioner, as due consideration must be had as to the style, design and adaptability of the machine used to produce a mixture acceptable to him.

If the materials are mixed by hand labor, the operation must be performed on platforms of water-tight construction by competent labor, in accordance with the following instructions:

The dimensions of the platforms must be such as to provide an area sufficient to allow the entire mixing operations to be done upon them in a thorough and complete manner, in accordance with these specifications, and will depend upon the volume of the material used in the batch; in batches requiring a full barrel of cement, the dimensions of the platform will not be less than ten (10) by twelve (12) feet, or its equivalent area, of suitable form, and no larger batches than these shall be made by hand labor.

The required quantity of sand will be spread upon the board or platform, dry, and covered with the cement, in its proper proportion, when the material shall be thoroughly mixed and incorporated, by turning it with shovels not less than six (6) times. When sufficiently mixed, the mass will be so spread and shaped as to form a basin for the water which is to be added to make the mortar. The required quantity of water will now be poured into the basin thus formed and incorporated with the dry substance, by the use of hoes and shovels, so as to prevent any loss of material. The mortar will then be spread over the surface of the platform in an even and regular layer, preparatory to the reception of the stone and gravel, which, having been previously drenched, will immediately be deposited and evenly spread over the mortar.

When the entire quantity of the aggregate has been deposited and spread on the platform, as above, the mass shall be thoroughly mixed by turning it over with shovels, not less than four (4) times, until every particle of the metal has been completely enveloped in mortar; and until every particle is so enveloped, to the satisfaction of the Engineer Commissioner or his agent the mixing process must be continued. The order of turning must be so regulated that the last turn made will place the material in a single pile at or near the center of the board, preparatory to its removal to the place for it in the work.

In removing the concrete from the platform care must be taken to preserve the incorporation, which can best be done by shoveling it from the base at the edges of the pile, toward the center of it, and at the same time cutting down the apex of the pile with a hoe or shovel, in such manner as to avoid an accumulation of loose stones.

Stone and gravel used in the concrete must not be drenched in the vehicles used to deliver it upon the platform, unless proper arrangements are made to drain the receptacles, but shall be wetted before they are placed therein.

Concrete shall not be used after it has shown evidence of beginning to set, and no concrete that has once set shall be used as aggregate for a new batch. The work of mixing and spreading shall be done as expeditiously as possible.

Any material condemned as unfit for use, or not conforming to the specifications, must be immediately removed from the site of the work. The contractor must provide suitable facilities to determine the quantities and quality of the materials used in the concrete, so that they may be readily ascertained at all times.

12. Laying.—Grade stakes of suitable character must be set to determine and regulate the grade for the material as it is deposited in the work, and straight edges or other equally efficient devices used to insure a regular and

uniform surface between the stakes, and as the concrete is placed upon the sub-grade it must be regulated with shovels by skilled labor to conform to the grade immediately upon its emplacement, and then rammed or tamped sufficiently in place to form a solid and compact mass. The labor necessary to spread and compact the concrete must be other than that required to mix it. In compacting the material in place the operation of ramming or tamping must be continued until the top surface is regular and the water in the mass begins to appear on the surface. No mortar that has been prepared for the purpose of forming a new batch of concrete shall be taken to plaster any rough or improperly tamped places that may appear in the base, as ramming or tamping must be the only means employed to obtain a smooth and regular surface.

The removal and placing of the concrete to grade should be performed in such a manner as not to disturb the uniformity of the mixture.

Any lack of compaction or evidence of inferior setting in the base will be sufficient reason to require its removal and new concrete substituted for it.

If required, the earth in the sub-grade will be dampened before the concrete is laid, and the concrete base shall be sprinkled and wetted as often as required during dry or hot weather to prevent damage from too rapid evaporation, etc.

No cement concrete base shall be laid during very cold or freezing weather without permission of the Engineer Commissioner and then only under such special regulations and instructions as he may think necessary.

No hauling must be done over or upon the base, for any purpose until after it shall have sufficiently set to withstand fracture, and, if necessary, the base shall be planked before any hauling is done.

The specifications in use in Peoria, Illinois, are as follows:

CONCRETE FOUNDATION.

28. **Thickness.** —Upon the sub-grade prepared in accordance with the specifications for grading, will be laid a concrete foundation six (6) inches thick after being compacted.

29. **Proportions.** —The concrete shall be composed of one (1) part by bulk of American Natural Hydraulic Cement, one and one-half (1½) parts by bulk of clean, sharp sand, and four (4) parts by bulk of broken stone.

30. **Intention of Proportions.** —The proportions herein specified are intended to produce a concrete in which the mortar will fill all the voids, and the proportions will be so adjusted that when rammed in place free mortar will flush to the surface.

MIXING AND SPREADING CONCRETE.

31. **Mixing Sand and Cement.**—The sand and cement shall be thoroughly mixed dry in a tight mortar box and then made into a mortar of the proper consistency and thoroughly worked over with hoes. Broken stone thoroughly cleaned of dirt, drenched with water, but containing no loose water in the heap, shall then be added to the mortar in the proper proportion. The concrete will then be turned and mixed until mortar adheres to each fragment.

32. **Consistency of Concrete.** —The concrete thus mixed shall have such a consistency that when rammed the mass will not shake like jelly; but will when struck, compact within the area of the face of the rammer without displacing the material laterally.

33. **Immediate Use of.**—The concrete thus prepared shall be immediately placed in the work. It shall be spread and thoroughly compacted by ramming until free mortar appears on the surface.

34. **Mixing and Laying.**—The whole operation of mixing and laying each batch of concrete shall be performed in an expeditious and workmanlike manner, and be entirely completed before the cement has begun to set.

35. **No Re-tempering.**—No re-tempering of concrete will be permitted, and concrete in which mortar has begun to set will be rejected.

36. **Conform to Grade.** —The upper surface of the concrete shall be made to conform exactly to the form of the pavement to be laid, and shall be made perfectly smooth by thoroughly brooming with wire brooms.

37. **Protection.** —As soon as laid, and before the top becomes dry, the entire surface of the concrete foundation shall be covered with one (1) inch in depth of clean sand to protect it from the sun and wind. The sand so spread shall be kept moist until the pavement is laid.

38. **Time for Setting.** —No driving over the concrete foundation will be permitted, and it shall be allowed to set for four days before any further work shall progress on the same, and any damage done by passing over it shall be repaired by the Contractor without extra pay.

39. **Minimum Temperature When Laid.**—No concrete shall be laid when the temperature at any time during the day or night falls below thirty-five (35) degrees Fahrenheit.

SPECIFICATIONS FOR CONCRETE CURB.

The specifications in use in Peoria, Ills., are as follows:

SPECIFICATIONS FOR CONCRETE CURB.

1. The curbing herein specified shall be constructed on.....
.....Street, from..... .....Street to.....Street.

2. The concrete curb shall be.....inches in thickness and.....inches wide, with the upper face corner rounded to a radius of one and one-half (1½) inches.

3. The curb shall be constructed on the ground in alternate sections, and the top edge shall conform to the line and grade given by the Engineer.

4. After the necessary excavation has been made along the line of the proposed curbing, there shall be laid a foundation of cinders twelve (12) inches wide and six (6) inches in thickness after being compacted; this bed of cinders to be flooded with water and thoroughly rammed to a true and even surface with a hand rammer weighing not less than forty (40) pounds.

5. Upon this bed of cinders shall be set the curb, which shall be constructed so as to form a solid mass, divided every seven (7) feet of its length into separate stones, and the concrete portion of which shall be composed of one (1) part best imported Portland cement, three (3) parts clean, sharp, well-screened sand, and five (5) parts hard limestone or granite crushed to such size that the fragments shall not be larger than one (1) inch in the greatest dimension.

6. A facing one (1) inch in thickness shall be constructed on the top and street face of the curb for a distance of.....inches from the top. This facing shall be composed of one (1) part best imported Portland cement and one and one-half (1½) parts fine granite screenings, and shall be carried up simultaneously with the concrete, same being plastered upon the front board of the frame immediately previous to placing the concrete. After the frame has been removed the facing shall be neatly troweled to a true, smooth surface.

7. The crushed granite shall be entirely free from dust or dirt, and broken to such size that no piece shall exceed one-fourth (¼) of an inch in its greatest dimension.

8. The curb shall be protected from the sun and wind by a covering of canvas or plank, or sprinkling it with water for at least twenty-four hours after completion.

9. The finished curb shall be of a uniform color, and sections which do not correspond in color with the remaining portion of the curb must be replaced. Any spalling or splitting off whatever of the finished surface of the curb, either at the joints or in the body of the stone, will be sufficient cause for rejection, and any rejected stone must be removed and replaced with a new one immediately. No patching, of any character, will be permitted.

10. The Contractor will be required to enter into a bond to guarantee the curb for a period of five (5) years after the completion and acceptance of the work against any settlement, cracks, discolorations, or any other defects due to bad materials or faulty workmanship which shall appear therein within the above period.

11. Circular curb stones will be constructed in the same manner as straight curb at the entrance to all alleys and driveways, and at the corners of all intersecting streets.

12. The sand and cement shall be thoroughly mixed dry in a tight mortar box and then made into a mortar of proper consistency and thoroughly worked

over with hoes. Broken stone or gravel thoroughly cleaned of dirt, drenched with water, but containing no loose water in the heap, shall then be added to the mortar in the proper proportion. The concrete will then be turned and mixed until mortar adheres to each fragment.

13. The concrete shall have such a consistency that when rammed the mass will not shake like jelly, but will, when struck, compact within the area of the face of the rammer without displacing the material laterally.

14. The concrete thus prepared shall be immediately placed in the work. It shall be spread and thoroughly compacted by ramming until free mortar appears on the surface.

15. The whole operation of mixing and laying each batch of concrete shall be performed in an expeditious and workmanlike manner, and be thoroughly completed before the cement has begun to set.

16. No retempering of concrete will be permitted, and concrete in which the mortar has begun to set will be rejected.

CHAPTER VI.

MACHINERY AND TOOLS,

It is not the object here to present anything upon the machinery used in the manufacture of cement, but upon the implements used in the making of concrete, cement mortar, and mortar and concrete work.

ROCK CRUSHERS.

It is frequently cheaper to buy and install a rock crusher with the necessary power to operate it than it is to buy the stone already crushed and pay for shipping it from a distance and hauling it upon the work.

Fig. 124.—Gates' Gyratory Crusher, No. 7½.

There are a good many kinds of rock crushers in the market; a few illustrating the different types will be presented here. Figure 124 shows

a Gates crusher. It is a gyratory crusher, having a heavy rotating head or cone within the shell, which gyrates eccentrically, crushing the stone between the gyrating head and the stationary outer shell.

Figure 125 shows a section through the machine more clearly illustrating the principle. It is claimed for this form of stone crusher that it

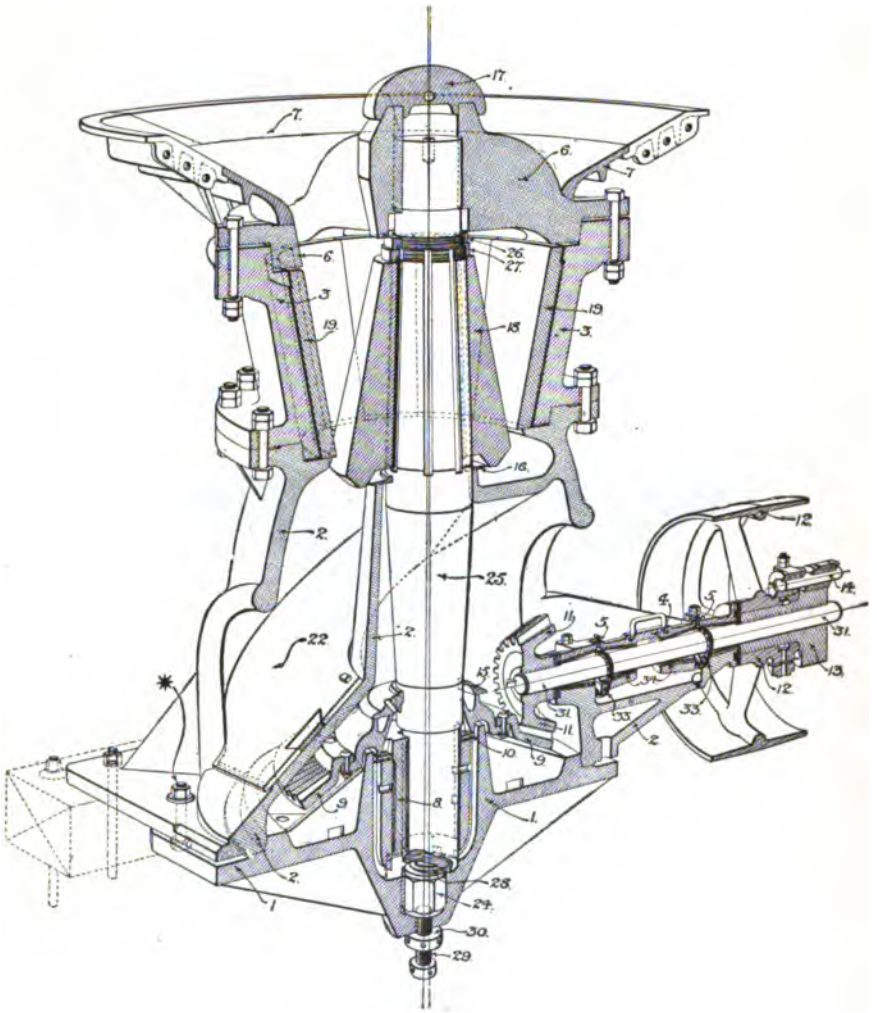


Fig. 125.—Section of Gates' Crusher.

The names of the several parts designated by numbers in the above illustration may be found in the following table:

1	Bottom Plate	11	Bevel Pinion	24	Octagon Step
2	Bottom Shell.	12	Band Wheel	25	Main Shaft
3	Top Shell	13	Break Hub	26	Upper Ring Nut
4	Bearing Cap	14	Break Pin	27	Lower Ring Nut
5	Oil Cellar Cap	15	Oil Bonnet	28	Steel Step
6	Spider	16	Dust Ring	29	Lighter Screw
7	Hopper	17	Dust Cap	30	Lighter Screw, Jam Nut
8	Eccentric	18	Head	31	Counter Shaft
9	Bevel Wheel	19	Concaves	33	Oiling Chain
10	Wearing Ring	22	Chilled Wearing Plates		

requires 30 per cent. less power under similar conditions to do the same amount of work which can be done by the other form of machine—the jaw crusher. It is also claimed that, because of the concave stationary surface and the impact of the revolving cone at the unsupported center of the masses of stone, a more perfect cubiform product is obtained.

Naturally it requires more power to break stone to one-half inch size than it does to break it to two and one-half inch size. This must be taken into account in ordering machines. The manufacturers of this machine claim that "The Gates' breaker will not require over one horse power per ton of rock broken per hour," for the hardest stone broken so as to pass a 2½ inch ring.

Figure 126 shows a section of the Austin portable crusher, which is a very simple machine of a similar type.

Figures 127 and 128 show view and section of the Farrel crusher, a very substantial compact machine of the jaw crushing type.

SCREENS.

Figure 129 illustrates revolving screens. The perforated screen sheets are easily removed and replaced when worn out, or they can be changed quickly when other sizes of stone are required.

Cheaper gravity screens can be used, but they are not quite so efficient in screening. They are of perforated sheet metal, as the revolving screens, but are in flat sheets and attached in the bottom of inclined chutes down which the crushed stone is allowed to slide dropping through the holes in the various sections as the size of aperture admits.

CONCRETE MIXERS.

There are numerous forms of concrete mixers, and many makers of the same form. At first engineers were averse to accepting machine mixed concrete, fearing inferior mixing, improper proportions of water and various other troubles. Now a large majority of engineers prefer machine mixed concrete, electing, however, to choose the form of mixer which shall be used.

The Drum Mixer.—The Ransome patents cover a drum mixer, a cylindrical machine having openings at either end and resting upon friction rollers. It is driven by cog wheels working in a cogged rim to the drum and the whole driven by steam, air, or electricity.

Inside this drum are kneading wings for mixing, and hinged shelves by which the concrete is lifted and thrown into a chute. These shelves are set for mixing or discharging by the movement of a single lever without stopping the machine. Figures 130 and 131 show the receiving and discharging ends of the machine respectively.

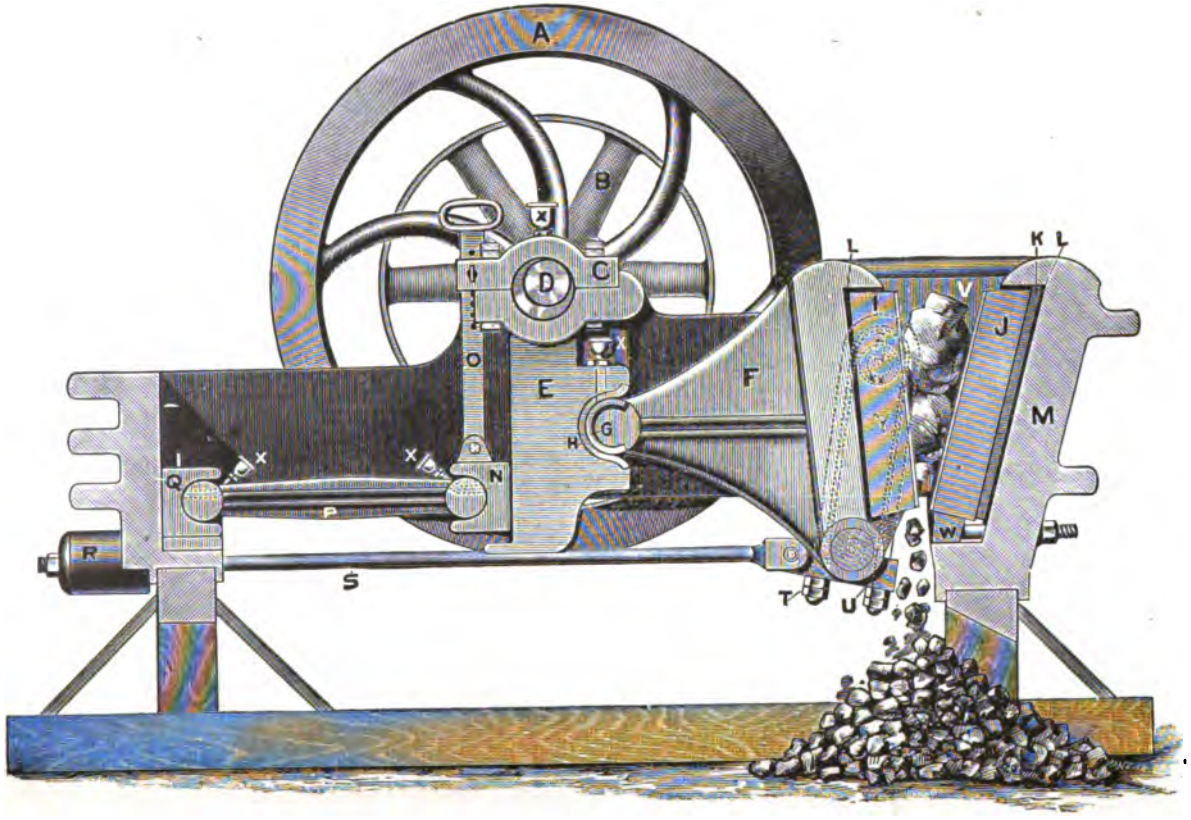


Fig. 126.—Austin Jaw Crusher.

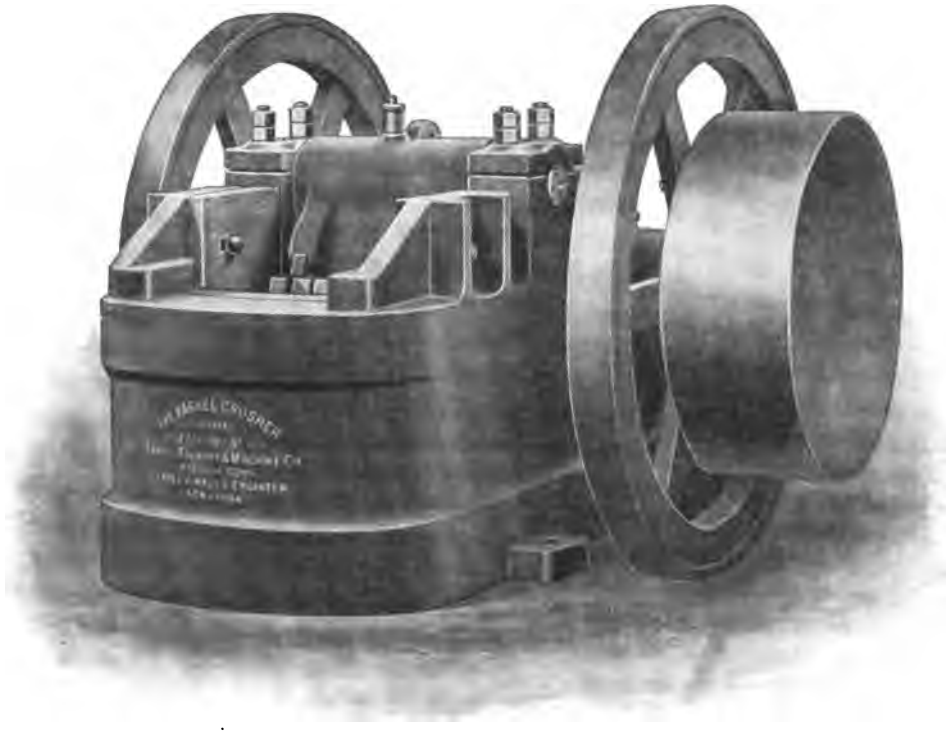
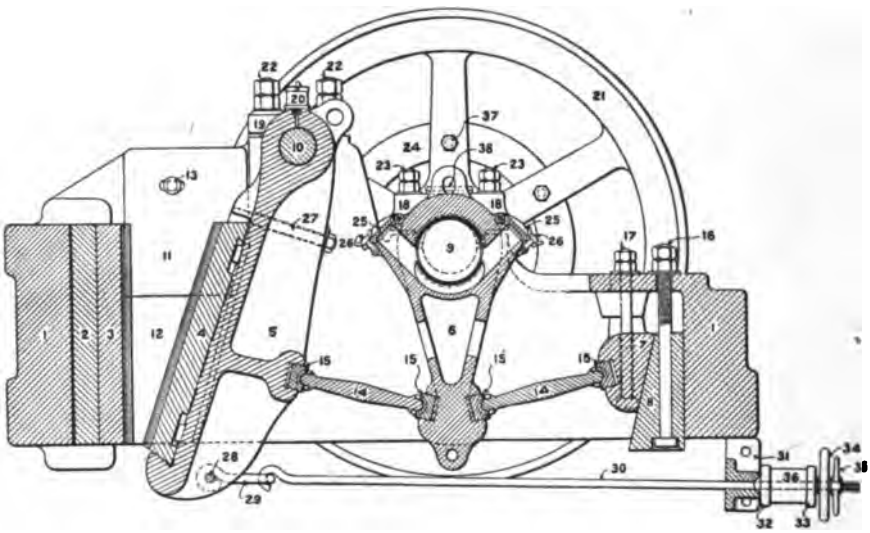


Fig. 127.—Farrel Jaw Crusher.



Sectional View of Farrel "Style B" Crusher

Name and Number of Parts.

1 Main Frame
2 Round Back
3 Fixed Jaw Plate
4 Swing " "
5 Swing Jaw
6 Pitman
7 Toggle Block
8 Wedge
9 Eccentric Shaft
10 Swing Jaw "
11 Upper Half Cheek Plate
12 Lower " " "
13 Bolt for " "
14 Toggle
15 Toggle Bearing
16 Bolt for Wedge
17 Bolt for Toggle Block
18 Cover " Main Bearing
19 " " Swing Jaw Shaft
20 Grease Cup
21 Balance Wheel
22 Bolt for Swing Jaw shaft cover
23 " " Main Bearing
24 Pulley
25 Grease Box Cover
26 Bolt and Thumb Screw
27 Bolt for Swing Jaw Plate
28 Shackle Pin
29 Spring Rod Shackle
30 Spring Rod
31 Spring Bar
32 Washer
33 Washer
34 Hand Wheel
35 Thumb Nut
36 Rubber Spring
37 Bolt for Pulley
38 Grease box cover on Main Bearing

Fig. 128.—Sectional View of the Farrel Crusher.

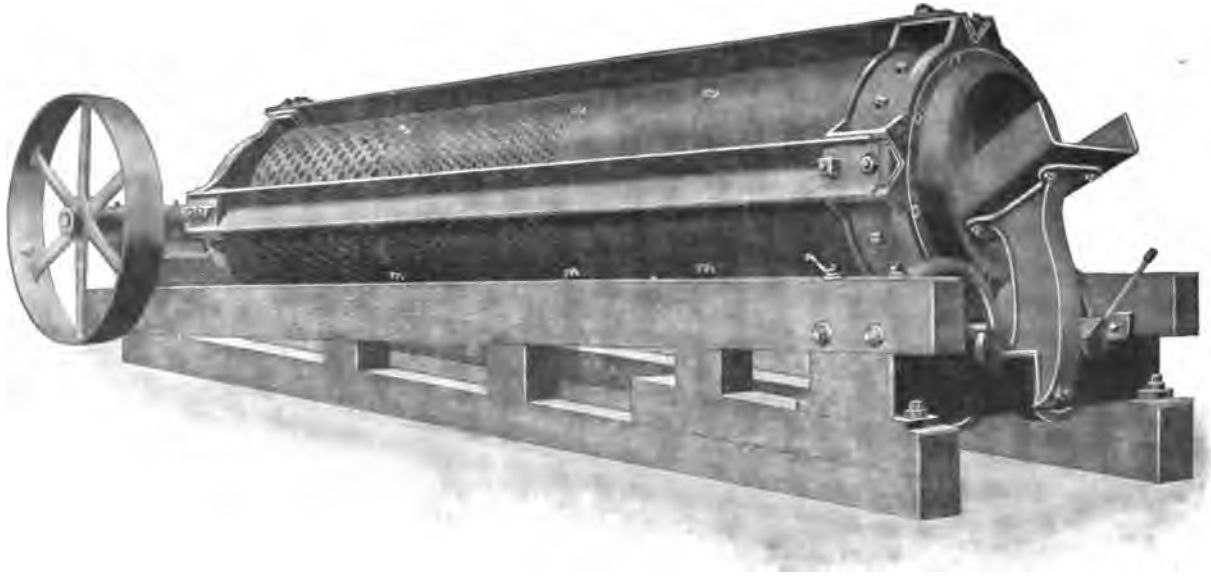


Fig. 129.—Gates' Revolving Screen.

"Passing through the drum and supported upon the truck is a folding chute which receives the concrete from the drum and delivers it to the wheelbarrow or other receptacle used for conveying the concrete away."

Inside of one minute the material has all been turned over thirty or forty times and is well mixed. This mixer will mix 200 to 400

Fig. 130.—Ransome Drum Mixer, Charging.

charges a day." Ransome claims to be able to mix concrete at a cost of 2 cents per cubic yard.

Smith Mixer.—The Smith concrete mixer consists of a revolving drum or double cone with horizontal axis, constructed with deflecting wings on the inside. The end of each cone is open, one serving as the loading end, the other for the discharge end. The concrete is visible during the entire period of mixing and can be discharged without stopping the machine. The thoroughness of the mixing depends upon the time spent or the number of revolutions given. Whenever the writer has seen the machine in operation it has been turning out an excellent product. Figure 132 shows the discharge end view of the Smith machine.

	No. 0	No. 1	No. 2	No. 2½	No. 4	No. 5
Standard charge, cubic feet	5	9	13½	16	21	28
Extreme capacity, cubic feet	6	12	17	21	23	35
Cubic yards mixed per hour, up to	5	10	16	20	22	35
Horse power required	3	6	8	10	14	18
Weight on skids with pulley only, in pounds	1,600	2,500	3,800	4,500	5,570	7,300

Fig. 131.—Ransome Drum Mixer, in Position of Discharging.

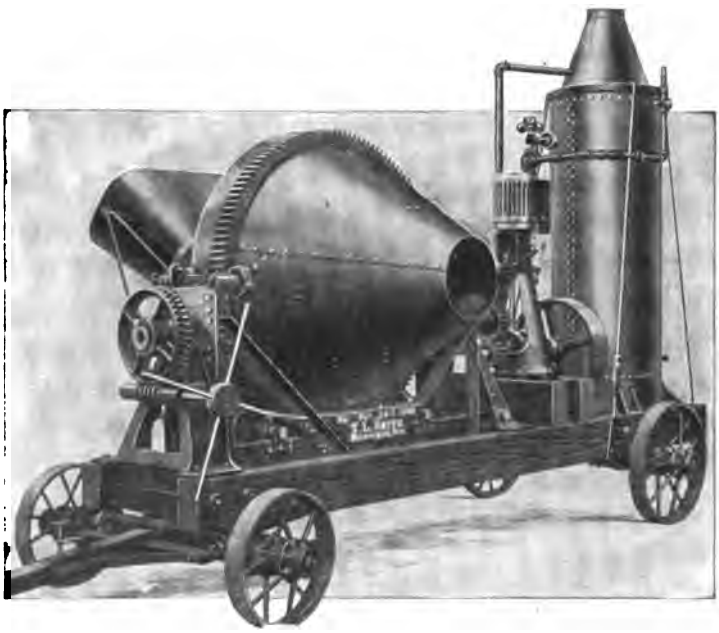


Fig. 132.—The Smith Mixer.

Campbell Mixer.—The Campbell machine consists of a horizontal circular pan revolving about a vertical axis and having a set of stationary plows fixed to a frame which can be raised or lowered into the pan. The pan carries the material against the plows and they throw the material back and forth in the pan as it revolves until the concrete is thoroughly mixed. A trap door in the bottom of the pan is then opened and the plows raised, while a scraping bar is lowered and the batch of concrete is scraped and dropped through the trap door into the transporting receptacle below. There are two sets of plows, one right hand and the other left hand.

"Time actually consumed in charging machine for one yard of concrete, completing the mixture and dumping the machine ready for the next batch, three minutes and ten seconds." Illustrations of the machine are given in figures 133 and 134. Specifications of size, weight and capacity are also appended.

Cubical Mixers.—There is a variety of cubical mixers, probably developed because the United States army officers at one time threw the weight of their commendations toward that form of mixer. This general form is supported so as to revolve upon a diagonal axis and thus throw the concrete mixture from one to the other of six different faces, each rapidly assuming a different angle to the horizontal and vertical planes as the cube revolves. One form of the cubical mixer is shown in figure 135. This is so arranged that it can be loaded at one end and discharged at the other, both operations taking place without stopping the machine's rotation.

Gravity Mixer.—Figures 136 and 137 show a simple gravity mixer which answers very well for some purposes. It consists of a funnel shaped receiving end attached to a box shaped chute having staggered rows of pins at frequent intervals along its length. It is also fitted with deflecting plates to throw the material from side to side as it descends through this chute, which is suspended at an angle of about 20 to 25 degrees from the vertical. The box is made in sections easily joined together so that various lengths, from four to ten feet, may be used for different classes of work and surrounding conditions. There is some doubt as to the thoroughness of the mixing obtained, also as to the even tempering of the mixture with water. There is much rough concrete foundation work, however, where this simple form of mixer might be satisfactory. Limited space allows the description of but one of the many other forms of mixers.

Dromedary Mixer.—The Dromedary mixer is a unique development of the two wheeled cart. The inventor evidently designed this to answer two purposes, first to utilize horse power to do his mixing, and second, to utilize for mixing, the power and time necessary to haul the material to

Fig. 133.—The Campbell Mixer, Steam Driven.

Fig. 134.—The Campbell Mixer, Horse-power Driven.

SIZE.	No. 1.	No. 2.	No. 3.
Weight on steel skids	3,000 pounds	4,000 pounds	5,500 pounds
Weight on wheels	4,000 pounds	6,000 pounds	.....
Weight of engine and boiler	1,400 pounds	1,700 pounds	2,700 pounds
Capacity per batch	⅓ yard	½ yard	1 yard
Batches per hour	30	30	25
Power required	3 horse-power	4 horse-power	6 horse-power
Diameter of mixing pan	6 feet 6 inches	9 feet	11 feet.

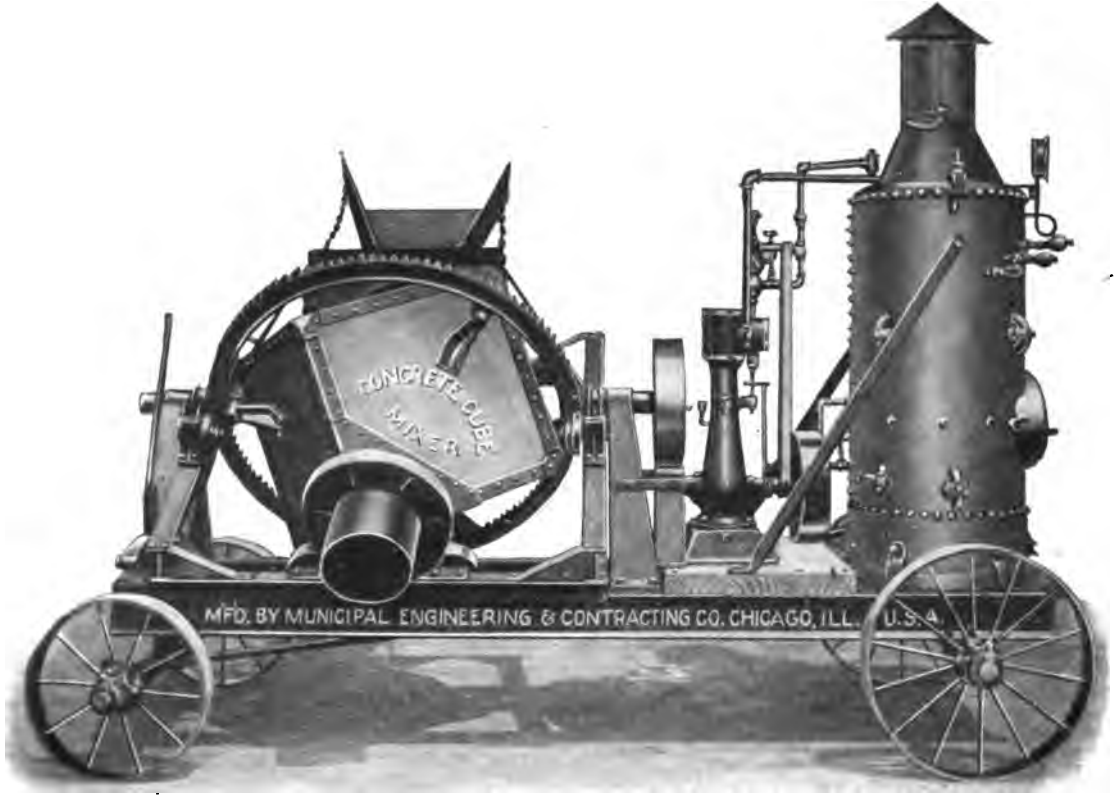
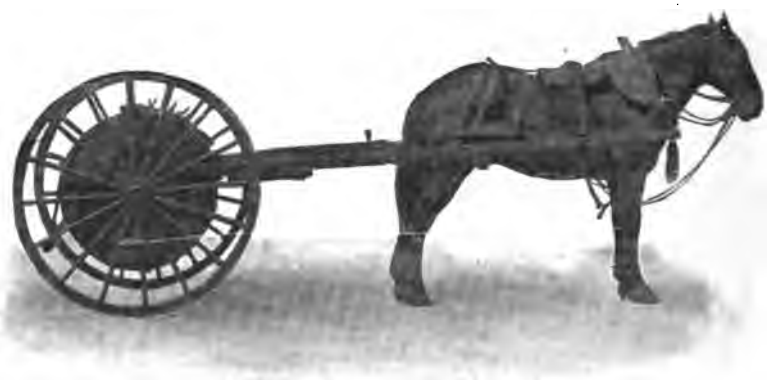


Fig. 135.—Cubical Mixer, Discharging Position.

Fig. 136.—Gravity Mixer, Full Length.

Fig. 137.—Gravity Mixer, With Short Section Out.

the point of construction. The machine consists of the two halves of a cylindrical drum, hinged together at one edge and closing by a spring and catch at the other. It is mounted upon the axle of a two wheeled vehicle. The drum is also so constructed that it can be made to revolve as the



LOADED

Fig. 138.—The Dromedary Mixer, Loaded.

wheels revolve, or it can be thrown out of gear and allowed to swing free. In one side is a door, through which the drum is loaded. When loaded, (see figure 138) it is thrown in gear and the horse hauls the dromedary drum to the point of discharge. The concrete is mixed by being carried

DUMPING

Fig. 139.—The Dromedary Mixer, Dumping.

up the side of the revolving drum and sliding and falling in thin sheets over the mass of material within. In unloading a bar is unlatched which causes

one-half of the drum to slide forward upon the frame work of the sulky and the batch is delivered upon the ground, thus leaving the drum in the position shown in figure 139, which gave it the name "Dromedary Mixer." It is especially useful where conduit or street work is being done and the material must be stored at intervals along the line of work, and must be conveyed some little distance to the point of construction. These machines are made in size for about one-half yard batches and cost $250.00 apiece, F. O. B., Washington, D. C.

MOLDS.

The first forms or molds used were simply constructed of planed lumber well braced and were for monolithic structures. The forms used by the Ransome Company in their concrete construction consist of short lumber frames reinforced with joists and bound together through the walls with rods and wires. These forms are raised for every three or four feet in elevation of the wall.

Thos. C. Farrell, of Washington, N. J., has designed a set of adjustable forms for monolithic concrete construction that is quite simple in adjustment. Metal shoes and "box caps" of cast iron shaped in the form of an extended H make the holders for two inch plank. Figure 140 illustrates their method of use under almost every condition to be met. The shoes and cross bolts leave holes and indentations in the walls which must be plastered up and smoothed over with cement mortar in order to make the wall have a smooth uniform appearance. By the aid of these forms but a comparatively small amount of lumber is necessary to carry on relatively large building operations. The operation is to set one course of ten inch planks around the entire structure as shown in the illustration, fill with concrete and tamp. Set up another course and fill with concrete, and so continue until four ten inch courses are filled. Then remove the bottom course and place it on top and proceed in this manner to the finish. By this method, the course to be tamped never exceeds ten inches in depth. The builder can reduce the thickness of the layers by making three layers of concrete to two tiers of plank if he so desires. These forms are easily set up, taken down and moved from one structure to another.

The Clark Patent Circular Mold is another form for monolithic construction. It consists of an inner and outer metal shield or form, braced and reinforced, leaving an annular space for the monolithic wall. It is especially designed to fill the demand for concrete silos, tanks, grain bins, manholes, etc.

BLOCK MACHINES.

The block machines are all very similar in general principles, but differ in minor mechanical applications.

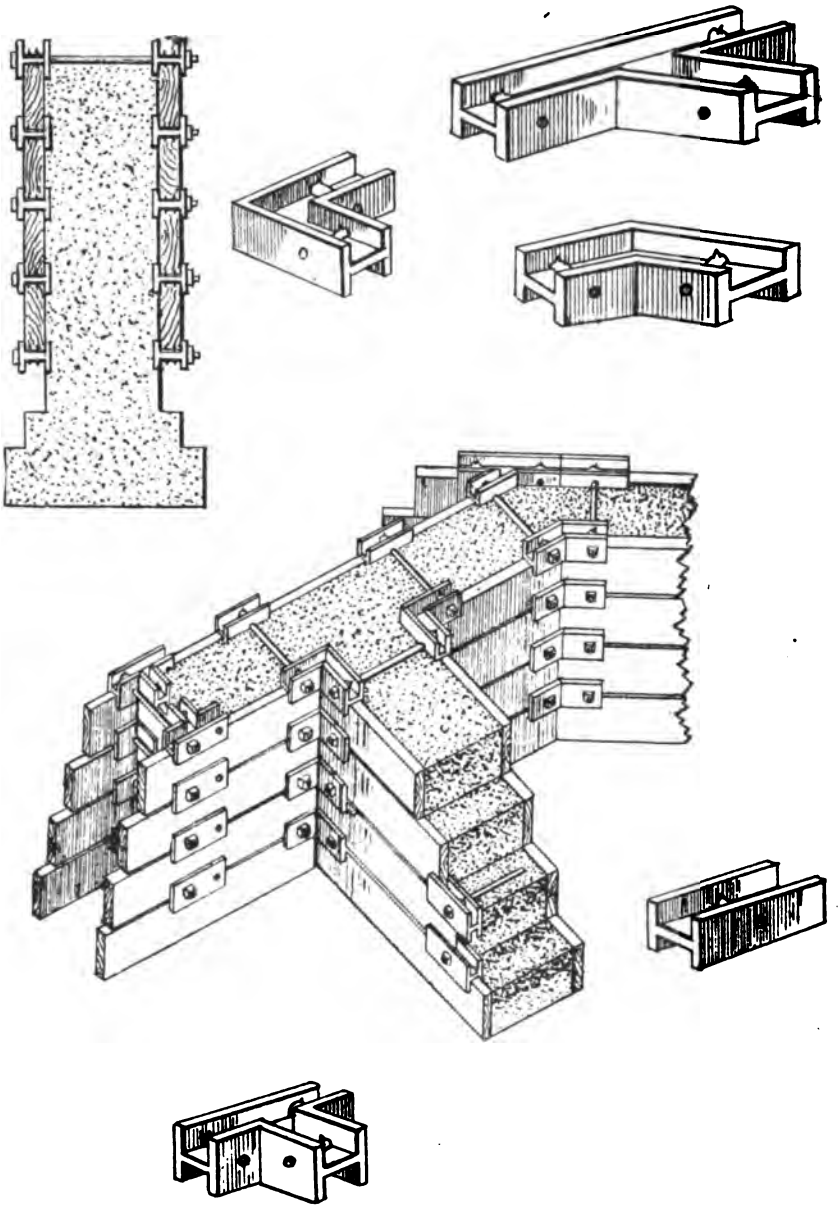


Fig. 140.—Farrell System of Molds for Concrete Wall Construction.

The Winget Machine, manufactured in Columbus, Ohio, is illustrated in figures 141 and 142. One ideal which all block machine makers strive to attain, is the elasticity in size and shape of their blocks. Most block machines attain this ideal to a greater or less degree. Another requirement is to keep strength and reduce material, which is accomplished by making the block hollow—this also makes walls which keep more equable temperatures within the structure, and which aid in preventing moisture reaching the interior surface of the walls.

Fig. 141.—The Winget Concrete Block Machine, Showing Block Ready to be Removed.

The Winget machine is so adjusted that the sides of a block can be faced with a richer mortar half or three-quarters of an inch thick. This gives a neater, smoother face to the stone and makes it less pervious to water. If desired, this outer shell can be colored, giving a very fair imitation of natural stone without being expensive in coloring matter. It is said that four men using this machine can produce 150 blocks per ten hours. The usual size is 9 inches by 10 inches by 32 inches. The Winget machine makes blocks having very sharp, neat, well defined corners, which is an essential to neat construction. The Winget Concrete Machine Company claim that blocks can be made with their machine and laid for about thirty cents apiece. Figure 143 shows the various shapes and patterns of blocks made in a Winget machine.

The Normandin Machine.—The Normandin machine also seems to be a very good machine. Figure 144 illustrates this machine. Similar to nearly all of the other block machines it has adjustable or exchangeable sides so that face designs can be substituted for plain faces.

The Palmer Machine.—The Palmer machine is one of the first designed of this class of machines. A great many neat houses have been

put up with the Palmer block. This machine, samples of blocks made upon it, and illustrations showing the use of its products are shown in figures 23, 24, 25, and 26.

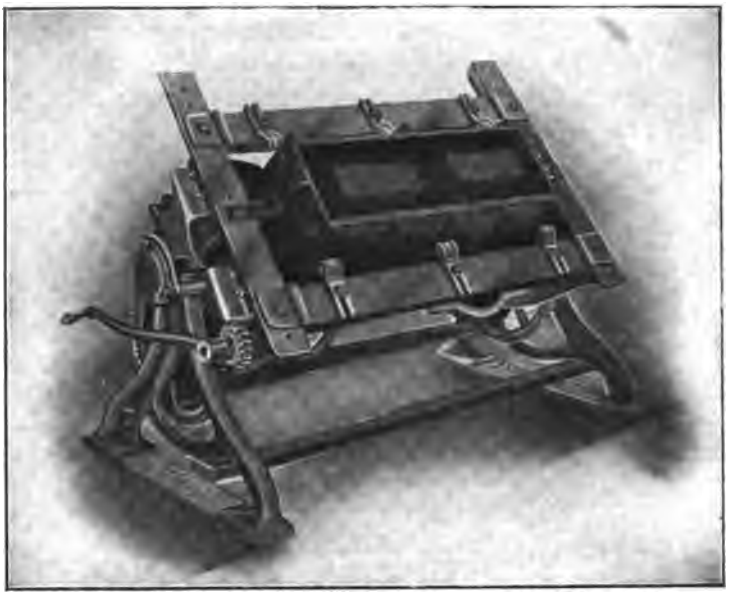


Fig. 142.—Winget Concrete Block Machine Empty.

The Dykema Machine.—The Dykema mold is illustrated in figures 145 and 146, the method of filling in figure 147, and the results accomplished, in figures 148, 149 and 150. The molds are made of sheet steel pressed into the desired shapes. There are seven lugs at each end of the side pieces allowing the adjustment of the end pieces in such a way as to permit the length of stone to vary from 19 to 25 inches. By the use of a special double core and dividing plate a still greater flexibiltiy of length is given varying from a least length of 4½ inches up to the 25 inches.

Fig. 143.—Collection of Concrete Blocks, Made on the Winget Machine.

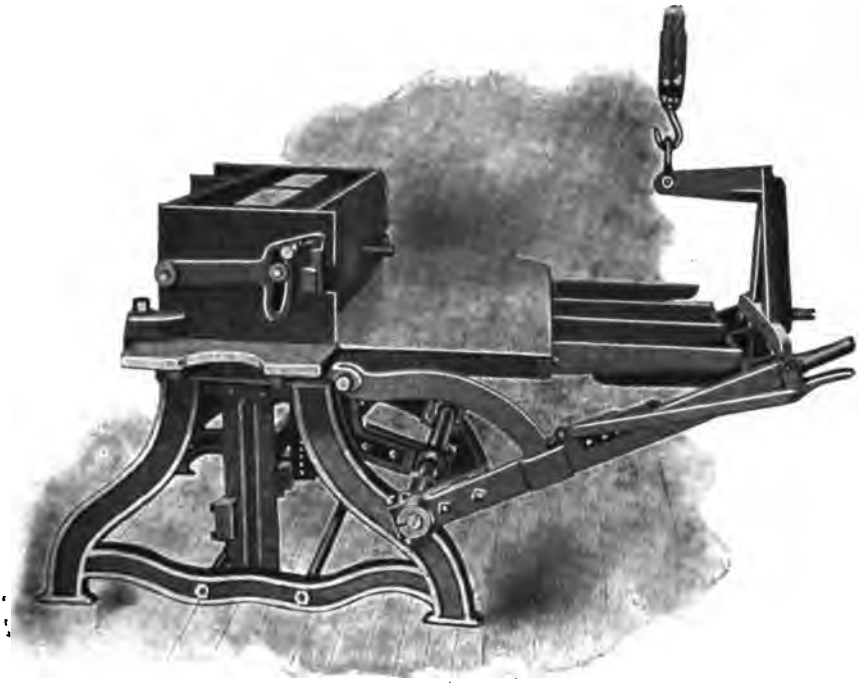


Fig. 144.—The Normandin Concrete Block Machine.

Fig. 145.—The Dykema Block Machine.

The stone manufactured by the Dykema process is made of very wet concrete, so wet that it will flow into place around the cores. Mr. Dykema claims that by this means he gets a denser concrete and at a considerable saving in labor. For work which compares with common brick work, the material is "struck" across the top of the mold after filling and troweled, but for finer natural stone effects, a surface coat of sand and cement is

added to the top of the block and fine sand or siftings of some natural stone are sifted over the surface producing the natural stone appearance. The form of the block, as shown in figure 149, affords an excellent means of handling the stone upon the wall. The company claim to do the work for the following prices, quoting from Dykema's "Stone Making."

Cost of Stone.—"Figures here given are from actual experience and based on the labor of men mixing by hand, and on the cost of labor and material in Grand Rapids.

The 12 inch stone lays 1.35 square feet in the wall, including a ½ inch mortar joint. This is equal to 30 bricks. One man can make 40 to 50 of these stone in a day, doing all the labor of setting up the mold, mixing the material and finishing the stone. With *"correct concrete"* 40 of these stones can be made from one barrel of Portland cement. Based on a day's work for one man a 12 inch stone figures as follows:

Labor	$0.04
Cement, 40 stone to the barrel, at $1.50 per bbl.	0.03¾
Gravel and sand	0.03
Total	$0.10¾

This is equal to $3.58 per 1,000 for brick. The 10 inch stone lays the same surface in the wall, 10 inches thick. The cost is as follows:

Labor	$0.03½
Cement	.03
Gravel and sand	.02½
Total	$0.09

These stones are sufficiently strong to replace any work which would otherwise be built of 12 inch brick walls."

Fig. 146.—The Dykema Block Mold.

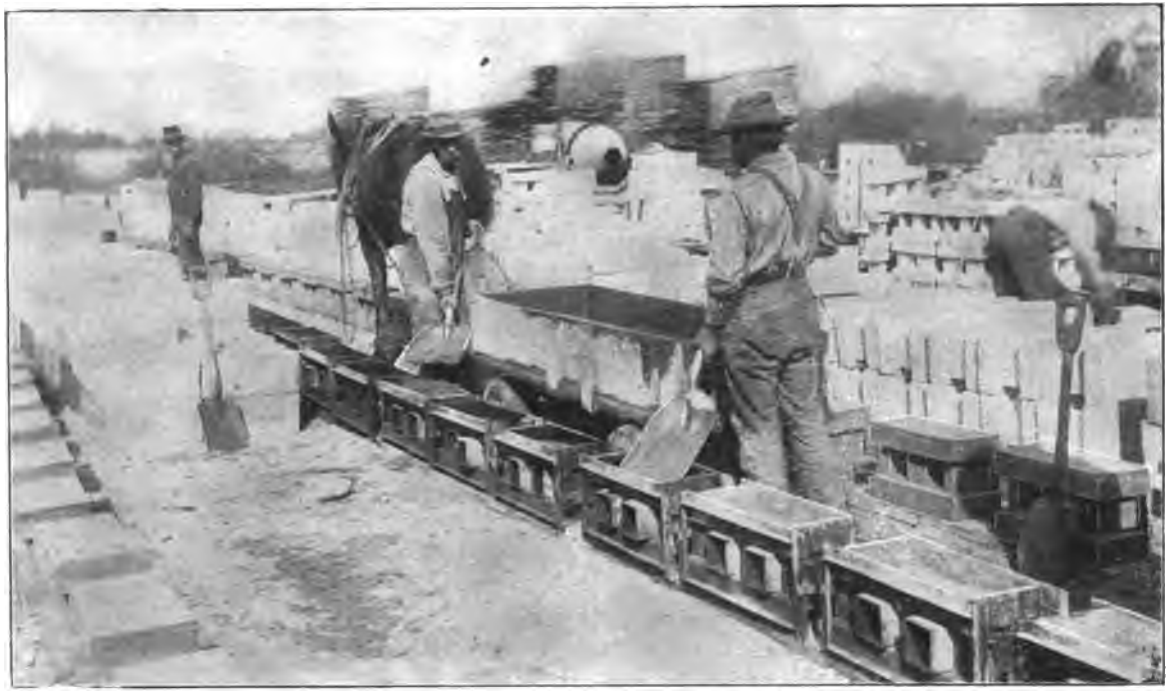


Fig. 147.—Filling the Dykema Molds.

For conditions at Columbus, these figures could not be substantiated. Assuming it possible to make 40 blocks a day, labor at $2.00 per day.

Labor, per block	$0.05
Cement, 40 stone to the barrel, at $2.00	.05
1½ yds. gravel and sand at $1.60 per cu. yd	.06
Cost per block	$0.16

To this must be added the interest and depreciation on the cost of the plant.

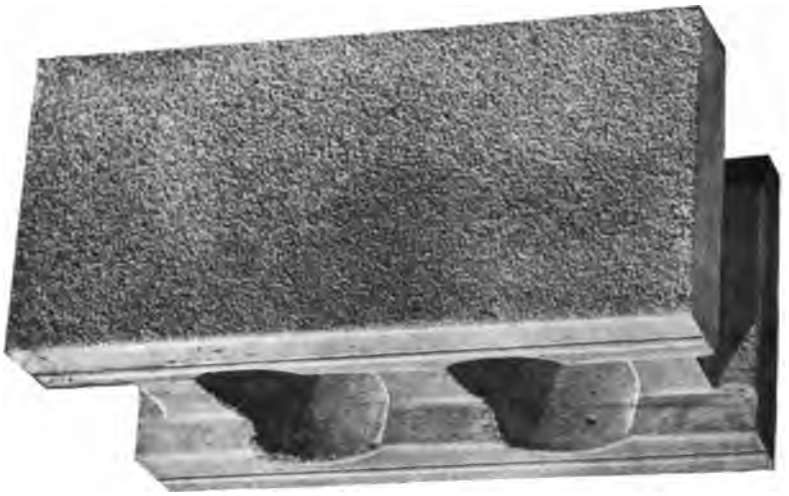


Fig. 148.—Dykema Block, Pebble Finished.

Fig. 149.—Dykema Block, Granite Finished.

Fig. 150.—Interior Structure of Dykema Block.

Fig. 150a—The Hayden Machine.

The Hayden Machine.—The Hayden machine, manufactured in Columbus, Ohio, is an automatic block machine in which the blocks are made face down, with the face in a horizontal position. This enables the operator to easily give a veneer facing of rich mortar to the block or to make the face of colored mortar in imitation of natural building stones. The machine is very compact and turns out blocks with corners and edges sharp and true. It automatically releases the block from the mold, delivering it upon a base plate to a support in front of the machine, ready to be carried away. The machine will make blocks 8 to 16 inches thick and 8 to 32 inches long.

Figure 150a illustrates the original Hayden machine. Experience has shown them that this machine is set too high and is not rigid enough. In the later machines now coming from their shops, they are reducing the height of the frame and making it much heavier.

TOOLS FOR CEMENT WORK.

Among the tools for the use of cement as in sidewalk, curb, street work, etc., come first the tools for hand mixing and handling. As these tools are common to many forms of work even to gardening, no illustrations or descriptions will be given. Among such tools are the shovel, hoe, rake and wheelbarrow.

Round and square iron tampers are the best for concrete work. Probably the square tamper is more serviceable for all kinds of work, because it will fit into corners. For some classes of work, such as facings in narrow places, the narrow or edge tamper is required. Figure 151 shows the foot of the square tamper. Prices are quoted by one maker ranging from $3.20 for the 6 by 6 inch to $4.80 for the 12 by 12 inch, all bases being ½ inch thick. These prices are subject to discount. Another maker quotes same tool from $1.00 upward.

The following figures illustrate the various implements used in concrete work, their names being sufficiently explanatory of the uses to which they are placed.

For the purpose of preventing slipperiness and to give a good foothold for horses, line rollers and indentation rollers are used upon the freshly troweled surfaces of walks, driveways and streets. Figures 156 and 157 illustrate these tools.

Concrete sidewalk tools are made in both bronze and iron. Some workmen prefer the bronze tool because it does not rust. Others prefer the iron tool because of the greater durability of iron. The bronze can be hardened, however, by a special process that makes it very durable.

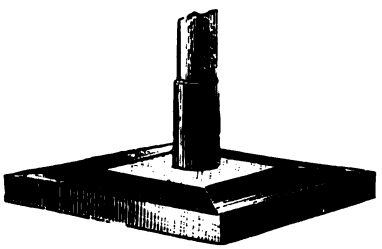


Fig. 151.—Rammer.

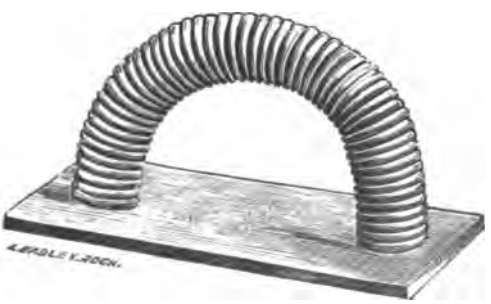


Fig. 152.—Bronze Name Stamp.

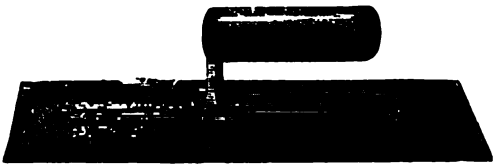


Fig. 153.—Smoothing Trowel.

Fig. 154.—Improved Sidewalk Edger.

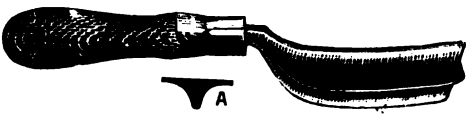


Fig. 155.—Jointing Tool.

Fig. 156.—Dotting Roller.

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Fig. 157.—Line Roller.

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